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Water Resources Evaluation Thousand Springs Basin Northeastern Neveda

Prepared for

LANDS OF SIERRA, INC.
A Subsidiary of Sierra Pacific Resources
Reno, Nevada

May 1989

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June 2, 1989

Bureau of Land Management
P. O. Box 831
Elko, Nevada 89801

Attention: Ms. Nancy Phelps-Dailey

Dear Nancy,

Enclosed for your review and comments are three copies of our draft report "Water Resources Evaluation, Thousand Springs Basin, Northeastern Nevada", May 1989. The report is in two volumes. Volume I is the basic report; Volume 2 is the appendices thereto.

This report was prepared by Woodward-Clyde Consultants, Oakland, California under the direction of M. B. Bennedsen, P.E. They performed the evaluation to assess the water resources available in the Thousand Springs Basin, and to prepare conceptual plans for how those resources should be developed to supply the water requirements of the proposed Thousand Springs Power Plant. The power plant is planned for construction by the Thousand Springs Generating Company. Lands of Sierra, Inc. has contracted to supply water to the power plant.

Your early review of this report will be appreciated. The conclusions and recommendations presented in the report are vital to the power plant project Environmental Impact Statement.

We appreciated the opportunity to have Messrs. Thackston and Fee of Woodward-Clyde Consultants, meet with members of the BLM staff April 25, 1989, to present a summary description of the conduct of the evaluation and the major conclusions and recommendations of the work. The comments of your staff at that time were most helpful in completing this report.

Please call me if you need additional information, or Mr. Bennedsen (at 415-893-3600) for technical concerns.

Sincerely,

John Saibini

John Saibini
Vice President
Resources Development

JS/cd

Enclosure

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1.0
EXECUTIVE SUMMARY

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This report presents the results of an investigation conducted to assess the quantities and locations of water resources present in the Thousand Springs Basin, in Northeastern Nevada, and to evaluate the environmental effects associated with various development alternatives that might be implemented to make some of those water resources available for the proposed Thousand Springs Power Plant. The power plant will be owned and operated by the Thousand Springs Generating Company. The proposed power plant will be a coal-fired, steam electric generating station, consisting of eight generating units at ultimate planned development. Each generating unit will have a net output capacity of 250 megawatts. The units are planned for initial startup at approximately 2-year intervals, and each unit is expected to have a 35-year operating life. Startup of the first generating unit presently is planned to be in 1994. Each unit will have an estimated maximum water requirement of 4000 acre-feet/year, or a maximum total plant requirement of 32,000 acre-feet/year. Other major planning factors pertaining to the project and the major conclusions of this investigation are summarized in this section of the report. It is noted that where the conclusions are quantitative in nature the quoted values are estimates based on presently available information.

The renewable water resources of the Thousand Springs Basin, on an average annual basis, are estimated to be on the order of 60,000 acre-feet/year, significantly exceeding the maximum projected annual water requirements of the Thousand Springs Power Plant, i.e., 32,000 acre-feet/year.

Lands of Sierra, Inc. owns practically all of the water rights that have been granted in the Thousand Springs Basin.

The perfected surface and groundwater rights owned by Lands of Sierra, Inc. in the Thousand Springs Basin significantly exceed the maximum projected water requirements of the Thousand Springs Power Plant. Also, certificated plus presently permitted groundwater rights owned by Lands of Sierra, Inc. exceed the maximum requirements of the power plant. Lands of Sierra, Inc. is contractually obligated to sell water to the Thousand Springs Energy Company on an as needed, priority of use basis. It is anticipated that surface waters covered by owned water rights beyond the amount required for maintenance of riparian and wetlands habitat will be managed and utilized for groundwater recharge, primarily by controlling reservoir releases to rates compatible with streambed infiltration rates. Lands of Sierra, Inc. will take all necessary actions to certificate its rights to presently permitted groundwater rights, as required to satisfy its obligations to provide water to the power plant.

It is planned that all water for power plant uses will be groundwater, to be provided from wells and wellfields. The wellfields and well locations within the wellfields will be selected and operated to prevent or minimize changes in the natural flows in the Thousand Springs Creek, and the effects of project water withdrawals on riparian habitat and wetlands along the Creek. As necessary, Lands of Sierra, Inc. will terminate its use of surface water for irrigation and make the water available for maintaining wetlands and riparian habitat along Thousand Springs Creek.

Wellfields will be required in two general locations to supply the total water requirements of eight units, as follows:

- The broad valley of the Toano Draw Subbasin where the power plant will be located. The renewable water resources available in this valley are estimated to be at least 8000 acre-feet/year,

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sufficient to supply the requirements of two units, and possibly a third unit.

- The broad valley of Thousand Springs Creek in the Gamble Ranch vicinity, upstream from Dake Reservoir and the Town of Montello, and extending upstream to near the confluence of Crittenden Creek with Thousand Springs Creek. The renewable water resources in the Gamble Ranch vicinity appear to be sufficient to satisfy the balance of the power plant needs, beyond what will be supplied from the Toano Draw area.

The principal aquifer to be utilized in each water source area is unconsolidated alluvium. In each valley the alluvium is estimated to extend to a depth of 800 feet or more, based on examination of available well logs and the results of surface geophysical studies conducted as part of this investigation, and in the Toano Draw area also on the results of exploratory drilling performed to correlate the surface geophysical data with drill cuttings and downhole geophysical data.

Precipitation falling within the watershed boundary of the Basin constitutes the gross renewable water resource of the Basin. Available information indicates there is neither surface nor groundwater inflow to nor outflow from the Basin across the watershed boundary, except at the downstream limit of the area, as adopted for this investigation, where Thousand Springs Creek discharges into Utah and the Great Salt Lake Basin.

The total area of the Thousand Springs Basin, as considered in this investigation, is approximately 1450 square miles, or approximately 930,000 acres. The average annual precipitation over the watershed is approximately 1 foot (12.2 inches). This estimate includes the orographic effects of the mountains around the perimeter and within the Basin. On a volumetric basis the average precipitation over the Basin is estimated to be about 945,000 acre-feet/year.

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The estimated current average surface water discharge at the downstream limit of the Basin (approximately the Utah state line) is about 4000 acre-feet/year. In addition, a Darcian analysis of groundwater flow through a cross section of the valley in the same vicinity indicates about 56,000 acre-feet/year is discharging into Utah.

Current net consumptive use of water in the Basin by irrigated agriculture is about 15,000 acre-feet/year. Other water uses in the Basin, including domestic and stock watering uses, are estimated to not exceed 200 acre-feet/year and no significant increase in this category of use is expected during the operating life of the power plant. For this investigation, relative to the water resources of the Basin, this category of use was considered a negligible amount.

Streamflow derived from the headwaters area of Thousand Springs Creek, i.e., the approximately 68 square miles of the Snake Mountains drainage above the Wilkins streamflow gaging station, is equal to about 25 percent of the precipitation on that part of the Basin, or an average of about 12,000 acre-feet/year.

Downstream from the Wilkins streamflow gaging station and the Highway 93 crossing of Thousand Springs Creek, the total average annual flow in Thousand Springs Creek decreases progressively indicating that there is relatively little runoff from other parts of the Basin that reaches Thousand Springs Creek. A substantial portion of the runoff from the headwaters areas of those other parts of the Basin percolates to the groundwater before reaching the Thousand Springs Creek.

The power plant will be located in the Toano Draw Subbasin. The total area of the Subbasin is about 252 square miles, or about 160,000 acres. Surface water discharging from Toano Draw to Thousand Springs Creek occurs infrequently and probably averages less than 1000 acre feet/year.

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Estimates of the average perennial recharge rate to groundwater from precipitation within this Subbasin range from about 6000 to 13,800 acre-feet/year.

Significant additional groundwater recharge may be contributed to the Toano Draw Subbasin or the alluvium underlying the Thousand Springs Creek from the area north and west and along Thousand Springs Creek.

It is estimated that about 6000 acre-feet/year discharges from the aquifer underlying the Toano Draw Subbasin into the alluvial materials underlying the Thousands Springs Creek area.

There currently is little use of water, for either stock watering or irrigation purposes, in the Toano Draw Subbasin.

A potentially large amount of groundwater may be present in the Paleozoic carbonate rocks underlying the alluvium in Toano Draw. It seems likely that this carbonate rock aquifer receives recharge from the alluvial aquifer, and that it discharges along deep flow lines beneath the mountains forming the eastern side of the Subbasin. The probable area of discharge of this deep flow is the alluvial aquifer underlying the Montello area and ultimately the Great Salt Lake Basin.

The depth to groundwater in the Toano Draw Subbasin varies from essentially zero at the north end of Toano Draw, where it joins Thousand Springs Creek, to about 160 feet at the power plant site, which is about 10 miles south of Thousand Springs Creek. Five miles south of the power plant site the depth to water is about 300 feet.

It is proposed that water for the first two generating units be supplied from a wellfield. This wellfield would tap the deep alluvial aquifer underlying the central part of the Toano Draw Valley. Of the 8000 acre-feet/year (maximum) required for those two units, it is believed that

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all will be replaced by natural recharge from precipitation. It is estimated that groundwater discharge from the northern end of Toano Draw may ultimately be reduced by about 6000 acre-feet/year and that the groundwater discharge to the underlying carbonate rock aquifer may be reduced about 2000 acre feet/year by this groundwater withdrawal.

To offset the progressive reduction in groundwater flow from Toano Draw to the Thousand Springs Creek underflow, it is proposed that the use of water for irrigation upstream from Twentyone Mile Reservoir will be curtailed by an equivalent amount. It is expected that there will be no significant environmental impacts to riparian habitat along any part of Thousand Springs Creek due to power plant water uses for the first two generating units.

Withdrawing water form the Toano Draw Subbasin aquifer will not significantly affect the rate of groundwater recharge within the Subbasin, because under presently existing conditions, there is practically no runoff from the Subbasin. Almost all runoff from the mountains surrounding the Subbasin currently infiltrates as it flows across the sediment filling the broad central valley of the Subbasin.

To supply water for power plant Units 3 through 7 it is proposed that wellfields be developed within the Thousand Springs Valley downstream from the confluence of Crittenden and Thousand Springs Creeks. Ultimately, this wellfield may extend southward to near the Town of Montello and east to near Dake Reservoir. A pipeline sized for serving five units (about 33 inches diameter) will be installed for transporting the water to the power plant site.

Present net consumptive water use for irrigation downstream from Twentyone Mile Dam is about 9000 acre-feet/year. This water use will be curtailed, as necessary, to offset the power plant water uses for Units 3 and 4, and part of Unit 5.

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Water for the balance of the requirements for Unit 5, about 3000 acre-feet/year not offset by reduced irrigation, plus all of the requirements for Units 6 and 7 probably will be offset by aquifer recharge from precipitation within the Montello Subbasin - by the Maxey-Eakin estimating procedure this amounts to about 12,000 acre-feet/year.

The quantity of groundwater presently discharging to Utah from the Thousand Springs Basin was estimated to be on the order of 50,000 acre-feet/year. Pumping of the Montello Subbasin alluvial aquifer ultimately will reduce the groundwater discharge to Utah by the amount the net pumpage exceeds the present net consumptive use in the Subbasin.

The average groundwater recharge rate to the Thousand Springs Basin as a whole has been estimated, using the Maxey-Eakin procedure, to be approximately 61,000 acre-feet/year. Thus it appears that the renewable resources of the Basin, on an average annual basis, are approximately twice the maximum water requirement of the power plant.

Present expectations are that the water resources within the Toano Draw Subbasin are adequate to supply a third generating unit, i.e., Unit 8. It is proposed that initial development of the water resources in this Subbasin be limited to the requirements of the first two units to be constructed, and that an aquifer monitoring system be installed and operated to assess the aquifer response to the withdrawals required for supplying those two units. When a decision is required concerning the source of water for Unit 8 - about 10 years (minimum) after the startup of Unit 2, according to the present project development plan - the data from the aquifer monitoring system should be evaluated to determine if the Toano Draw aquifer can sustain the production required for Unit 8. If not, the unused resources in the Montello area aquifer can be developed for this purpose.

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Aquifer transmissivities were estimated for both the Toano Draw and the Montello area aquifers. For the Toano Draw Subbasin aquifer transmissivity estimates range from 3000 to 50,000 gallons per day/foot. For the Montello area the estimates are in the range of about 130,000 to 200,000 gallons per day/foot.

Numerical modeling of the Toano Draw alluvial aquifer, to portray the aquifer response to several wellfield development alternatives, indicated that the environmentally most favorable plan would be to supply water for three generating units from a single wellfield south of the power plant site. Maximum aquifer drawdown estimated for this case would be on the order of about 70 feet and would occur in the wellfield area. The indicated groundwater level decline at the north end of the Toano Draw aquifer, along Thousand Springs Creek, would be negligible in this case.

Water quality in both the Toano Draw and the Montello area aquifers is acceptable for power plant uses. The total dissolved solids (TDS) content of the groundwater ranges from about 200 to 500 mg/L within the Toano Draw aquifer. In the Montello area aquifer the TDS is generally higher. The silica content of the groundwater is relatively high in the Toano Draw area, up to about 80 mg/L, whereas in the Montello area the silica content of the groundwater is significantly lower, ranging from about 12 to 34 mg/L.

An existing irrigation well, about 3 miles north of the power plant site, and a pilot production well, installed as part of this investigation about 2 miles south of the plant site, are both available and adequate to supply construction water for the first power plant unit.

In this reconnaissance level investigation of the Thousand Springs Basin as a whole, surface geophysical survey techniques were found to be useful, expedient, and economical for identifying areas with substantial thicknesses of potential aquifer materials. These geophysical techniques

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are believed applicable and appropriate for guiding the locations of more detailed exploratory drilling investigations that should be completed before starting project wellfield developments.

Wellfield development for the first two generating units should start with a detailed surface geophysical survey of the area south of the power plant site that was identified in this investigation as potentially favorable for the purpose. Pilot borings should be drilled in the areas indicated as most favorable from the geophysical survey to check the validity of the geophysical survey results. These surveys and exploratory drilling should be undertaken at least 2 years before planned startup of the first generating unit. Placement of production wells should be based on the conclusions of the two investigatory techniques.

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2.0 INTRODUCTION

2.1 PROJECT OVERVIEW

This report presents the results of a study to assess the water resources of the Thousand Springs Basin, in northeastern Nevada (see Figure 2-1). The study was performed as part of the process of preparing the Environmental Impact Statement (EIS) for the proposed Thousand Springs Power Plant Project. A major objective of the study was to provide information needed for developing the groundwater resource of the Basin and evaluating the hydrologic balance with and without the proposed power plant. For this purpose, it was necessary to identify the most likely sources of water for supplying the power plant requirements, and prepare conceptual plans for how those resources would be developed and utilized. The proposed power plant, at ultimate planned development, will contain eight, coal fueled, 250-megawatt generating units. Each generating unit will require an average of about 4000 acre-feet per year of makeup water to support its operation.

It is believed that the total water resources of the Thousand Springs Basin are derived from precipitation falling within the watershed boundary of the Basin. An investigation of groundwater levels in the limited number of springs and wells within and surrounding the Basin (Section 4.0) found that the hydraulic gradients of the water table on both sides of the topographically elevated watershed divide were consistently away from the divide, suggesting that there was no flow across the line marking the divide.

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For the purposes of this study, the basin of concern lies upstream from the United States Geologic Survey's (USGS) Montello streamflow gaging station, located about one mile upstream from where the Thousand Springs Creek flows into Utah and the Great Salt Lake Basin. Outflow from the Thousand Springs Basin at the Montello station consists of surface water flow in the stream channel, which is measured by a recording gage, and underground flow. In order to derive the basin hydrologic balance, the total basin precipitation was estimated and equated to total evapotranspiration within the Basin plus surface and groundwater outflow. It is noted that within the Basin as a whole there is, and has been historically, relatively little water development and use when considered in relation to the total water resources of the Basin. Therefore, when considering long-term trends, the groundwater basin as a whole is essentially in equilibrium with the climatic regime; i.e., precipitation infiltrating to the groundwater is essentially equal to the long-term groundwater discharge from the Basin. The minor inequality is the result of the relatively small net amount of groundwater extracted for ranching operations - primarily irrigation uses - within the Basin.

It is expected that the power plant water requirements will be supplied from wellfields that tap the groundwater resources of the Basin. As a result, the present equilibrium in the groundwater system will be modified. One result of this modification is expected to be that some of the groundwater which presently discharges from the Basin will instead be captured by the project wellfields. An important focus of this study was to estimate the average annual stream flow in the Thousand Springs Creek under present conditions, the extent to which this flow contributes to groundwater recharge, and how recharge rates will change after the power plant begins operation.

2.2 PURPOSE OF REPORT

This Water Resources Evaluation Report has been prepared by Woodward-Clyde Consultants (WCC) to provide the information needed to evaluate the

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groundwater resources available for supplying the proposed Thousand Springs Power Plant. Specifically, the principal purpose of the report is to provide the detailed geologic, hydrogeologic, and hydrologic data and analyses required to characterize the groundwater resources and flow systems in the Thousand Springs Basin. Included in this report are assessments of potential groundwater system yields, recharge rates, streamflow characteristics, the interaction between surface water and groundwater systems, and water budget analyses. An additional objective of the report is to provide an evaluation of the effects of project-related groundwater withdrawals on existing water uses, basin productivity, groundwater levels, water quality, and the existing environment. For this report, special emphasis was placed on characterizing the groundwater system of the Toano Draw Subbasin, relative to the water needs of the first proposed power plant unit, i.e. approximately 4000 acre-feet per year. However, the report also includes an evaluation of the regional water resources for supplying the water needs of the power plant as it expands to its planned ultimate size of eight units, each requiring approximately 4000 acre-feet per year, and the potential water resources impacts of pumping at those levels (up to approximately 32,000 acre-feet of water per year) for the anticipated 49-year life of the project from initial startup of the first generating unit to final shutdown of the eighth generating unit.

2.3 OVERVIEW OF SCOPE OF WORK AND REPORT ORGANIZATION

The scope of this investigation has included many types of geologic and hydrologic data acquisition, compilation, mapping, and analyses. The characterization of aquifer thickness and extent was based on regional geologic mapping, extensive geophysical surveys, compilation of existing well logs, and exploratory drilling and logging of new wells, as described in Section 3.0. A total of 12 new wells was installed by WCC for groundwater monitoring and aquifer testing, as described in Section 4.0. The hydrogeologic setting of the Basin was characterized, based on a comprehensive analysis of groundwater level data from approximately 70

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wells and results of six aquifer pumping tests. These data supplement information provided by the geologic characterization and by results of aquifer tests reported by previous investigators, notably Rush (1968) and Guyton (1982). Groundwater quality trends were analyzed and mapped, and are discussed in Section 5.0 relative to elucidating the flow system. Concentrations of hydrochemical constituents in groundwater that are considered significant to the power plant water supply are also described in Section 5.0.

Available precipitation records and streamflow measurements were compiled and analyzed to estimate basin, and selected subbasin, runoff and recharge rates. These data have been incorporated into hydrologic budget analyses of the Basin and selected subbasins, as described in Section 6.0.

A three-dimensional, numerical groundwater flow model was developed for the Toano Draw Subbasin and vicinity, for quantitative evaluation of the water resources described in Section 7.0. This computer model was applied to simulate the drawdown effects of anticipated project wellfields, as described in Section 8.0. In addition, Section 8.0 contains the results of analytical modeling that was performed to estimate the effects of pumping in the area of Montello Valley. The Montello area was outside the boundary of the numerical flow model.

Project related water rights issues are discussed in Section 9.0. Results of the flow modeling analyses have been used to assess the potential for the various hypothetical wellfields to meet the plant water requirements, and the potential impacts of pumping on existing water rights, supply wells, streamflow, springs, and riparian habitat. Descriptions of these estimated environmental impacts and the potential water quality impacts of groundwater extraction are described in Section 10.0.

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Hydrologic monitoring plans for precipitation, streamflow, groundwater extraction quantification, groundwater levels, water quality and subsidence, designed to establish baseline conditions, and to detect and evaluate project related effects of plant operation as they occur, are included in Section 11.0. Section 12.0 of this report provides recommendations for the next phase of work for development of the groundwater supply wellfields and systems.

The appendices to this report provide basic data, and descriptions of the methods of data collection, that were used as a basis for the findings of the report.

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3.0
GEOLOGY AND GEOPHYSICS

Geologic and geophysical mapping was conducted within the Toano Draw Subbasin to provide hydrogeologic information regarding groundwater availability for the proposed Thousand Springs Power Plant. Two objectives were established for this task:

- Identify and describe surface geologic deposits and structural features that might affect groundwater availability within the Subbasin.

- Provide a preliminary estimate of the areal extent, thickness, and depth of the principal aquifer and aquitards within the Subbasin.

These objectives were accomplished by integrating both geologic and geophysical data. Surficial deposits and structural features were identified by review of available literature, aerial photographic reconnaissance, and field mapping. Estimates of aquifer dimensions were established by surface and borehole geophysical surveys and modeling correlated to geologic mapping and petroleum and water well data.

The geological and geophysical studies were conducted by Woodward-Clyde Consultants personnel. Time Domain Electromagnetic (TDEM) and Dipole-Dipole Resistivity surveys and modeling were performed by Blackhawk Geosciences, Inc. of Golden, Colorado.

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3.1 GEOLOGIC MAPPING

The geologic mapping was conducted in three principal phases: 1) available geologic data including published reports, well geophysical and lithologic logs, and consultants' reports were reviewed, 2) aerial photographs were examined, and 3) field mapping, consisting of ground reconnaissance and an aerial overflight, was done to augment and verify aerial photograph interpretation.

3.1.1 Available Geologic Data

Although little geologic mapping has been done in the Toano Draw Subbasin, several reports are available which provide basic data important to the understanding of the geology of the study area.

Eakins, Maxey, and Robinson (1951) and Eakins and Maxey (1951) authored two groundwater hydrology reports regarding the Goshute and Antelope Valleys to the south and the Clover and Independence Valleys to the southwest. These reports, which were published within a compilation of similar studies concerning the hydrology of eastern Nevada, contain cursory information about the regional geology.

Rush (1968) conducted one of the first geologic reconnaissance projects in the area. The purpose of the study was to evaluate the water resources of Thousand Springs Basin, an area which encompasses the adjacent Montello-Crittenden Subbasin to the east, the Rock Spring Valley to the north, the Herrell Siding Subbasin to the west, and the Rocky Butte area at the confluence of Twentyone Mile Draw and Thousand Springs Creek to the northeast, as well as, Toano Draw. Rush developed a preliminary geologic map which roughly delineates Paleozoic rocks, Tertiary volcaniclastic deposits, and unconsolidated sediments. In addition, Rush shows several Basin and Range style normal faults along the western side of Toano Draw and along the southeastern flank of the HD Range north of Thousand Springs Creek. Rush described four broad lithologic units based primarily on

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hydrologic properties: carbonate rocks, noncarbonate rocks, and older and younger alluvium. Rush also speculated that a large volume of water is moving through the carbonate rocks in the north part of the basin and beneath the channel of Thousand Springs Creek.

The geologic map of Nevada (Stewart and Carlson 1974), provides generalized stratigraphic and structural information about the study area at a scale of 1:500,000. The Toano Draw Subbasin is located in a zone of transition between the northern portion of the Basin and Range province and the Snake River Plain to the north. Typically, the Basin and Range province is characterized by well-defined, linear, north-trending valleys and mountain ranges bounded by normal faults. However, as shown on this regional map, the Toano Draw Subbasin is broad and the adjacent mountains are less linear than those to the south. Also, as on the Snake River Plain, volcanic rocks, including volcaniclastic sediments, are more abundant than in the rest of the Basin and Range Province. This map indicates that surficial deposits of the Toano Draw Subbasin primarily consist of volcaniclastic sediments with alluvium occurring only in the stream channels.

A 1:100,000 scale geologic map (Hope and Coats 1976) of Elko County maps the volcaniclastic deposits in greater detail and identifies lithologies of Paleozoic and Mesozoic rocks which occur in the mountains surrounding the study area. Surficial deposits of the Toano Draw Subbasin are more accurately shown to consist of a large volume of volcaniclastic sediments interfingering with a large alluvial fan complex which surrounds the Toano Draw channel.

Woodward-Clyde Consultants (1981, 1982) performed preliminary geologic and geotechnical investigations within the Toano Draw Subbasin to determine geological conditions at the proposed plant site, an ash disposal site, and potential borrow areas. The investigation included geologic reconnaissance and mapping, subsurface drilling, and laboratory analysis. These

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investigations concluded that surface materials are silt at the ash disposal site and cemented pyroclastic sediments at the proposed plant site.

Erwin (1980) produced a 1:250,000 scale bouguer gravity map covering the Wells 2° Sheet. This map, although regional in scale, provides important information about the structural configuration of the Paleozoic basement within the Toano Draw Subbasin. A revision of the gravity map by West (1987) shows the following additional faults: north-trending Basin and Range normal faults along the eastern and western margins of the Toano Draw Subbasin, a northwest-trending normal fault along the southern basin margin bounding the northern Pequop Mountains, and several northeast-trending faults at the southern end of Twentyone Mile Draw and to the north of Thousand Springs Creek in the northern part of the valley. West (1987) also indicates that the upthrown sides of the range-front faults at the margins of the Subbasin are comprised of relatively shallow occurrences of bedrock or piedmont fronts. This suggests that the bedrock was eroded at some time in the past and has subsequently been elevated along the faults.

Guyton and Associates (1982) performed an initial study of the ground water conditions in the Thousand Springs Creek area. The report subdivides the rocks in the area into three major categories: noncarbonate consolidated formations, carbonate formations, and unconsolidated sediments. The unconsolidated rocks are further subdivided into four categories: lake deposits, tuffaceous sedimentary material, older alluvium, and recent alluvium. The lake sediments, which were deposited in late Pleistocene time and reached an upper elevation of 5100 feet, are located primarily within the Montello valley to the east.

A report was prepared by the Bureau of Land Management (1986) in anticipation of a land exchange between Lands of Sierra and the BLM. The report supplies lithologic descriptions of the rock units, a brief history of the regional geology, and an assessment of the mineral potential of the land considered for the exchange.

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Additional geologic information was gathered from petroleum and water well logs and a report summarizing well log data (Guyton and Associates 1982). The water well logs were provided by the Nevada State Engineer's Office, Carson City, Nevada and R. D. Reynolds Drilling, Inc., Wells, Nevada. Petroleum logs were obtained from Nevada Bureau of Mines, Reno, Nevada and the Petroleum Information Corporation of Bakersfield, California.

3.1.2 Aerial Photograph Reconnaissance

Interpretation of geologic features using aerial photographs is a standard procedure in most geologic evaluations. Aerial photographs provide an expeditious means of conducting an initial investigation of a large area, such as the Toano Draw Subbasin. The aerial photographic reconnaissance is supplemented by field mapping to verify observations.

A total of 285 black and white, stereoscopic aerial photographs at a scale of 1:36,000 were purchased from the U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota. The photographs were taken along two flight lines: GS-VBNM, along the eastern portion of the Thousand Springs Valley, flown in 1966, and GS-VBST, along the western portion of the Thousand Springs Valley, flown in 1967.

Aerial photographs were examined in stereoscopic perspective to map surficial stratigraphic units and structural and geomorphic features. Stratigraphic units are differentiated based on several criteria including texture and pattern, tonal contrast and color, aerial extent, and vegetation.

Structural features such as faults, folds, joints, and lineaments are identified based on several criteria defined by Ray (1960). These criteria include alignments of vegetation; straight stream segments; knickpoints or waterfalls across streams; alignments of ponds, springs, lakes, and marshy

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areas; linear changes in photographic tone, drainage, or erosional texture; tonal changes due to vegetation differences along a linear feature; alignments of topography such as facets, spurs, ridgelines, and scarps; and linear depressions, such as saddles, and rectilinear depressions.

Geomorphic features such as alluvial fans, bajadas, landslide scarps, ancient lake shorelines, and lake barrier bars are identified primarily by their shape and also their association with adjacent deposits and features. For example, alluvial fans generally have a convex, fan shape with the narrow apex at the range front and the broader distal lobe extending toward the valley center. Bajadas occur at the base of a mountain front and are characterized by a broad, nearly planar surface resulting from the coalescence of alluvial fans.

Preliminary geologic interpretations were recorded on mylar overlays attached to individual photographs. These observations were later checked during field reconnaissance and transferred to a topographic map base at a scale of 1:100,000.

3.1.3 Geologic Field Reconnaissance

This phase of the geologic mapping involved ground reconnaissance and a fixed-wing aerial overflight. The field mapping was conducted during two site visits, from July 14 to 18, 1988, and August 29 to 31, 1988. The aerial overflight was made on the morning of August 30, 1988.

The purpose of field mapping was to provide verification of the aerial photographic interpretation and to gather field data that could not be obtained at the scale of the photographs. The mapping consisted of a series of traverses across the Toano Draw Subbasin and a loop around the perimeter of the Subbasin using a four-wheel-drive vehicle. Locations were plotted using aerial photographs, 7.5 minute topographic sheets at a scale of 1:24,000, and 2° topographic sheets at a scale of 1:100,000.

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An aerial overflight, using a fixed-wing aircraft provided by Sierra Pacific, provided closer views than aerial photographs of areas inaccessable by four-wheel-drive.

Observations from geologic field mapping were incorporated with aerial photographic interpretations and available literature to construct a geologic map at a scale of 1:100,000 (Figure 3-1).

3.2 GEOPHYSICAL DATA

3.2.1 Regional Data

A review of the available regional geophysical data, both gravity and aeromagnetics, was conducted prior to development of the geophysical field program. This information was used to concentrate efforts during the field reconnaissance in areas indicated by the previous work to be geologically favorable for substantial quantities of groundwater.

3.2.1.1 Gravity Data. Regional Bouguer gravity data for the Toano Draw area is depicted on a 1:250,000 scale map of the Wells 2° sheet by Erwin (1980). Supplemental interpretation of these data by West (1987) was also obtained for this investigation. Regional gravity data provides general information about the depth and geometry of basins, regional and local structures, and the predominant materials in the area. The Basin and Range Province is especially conducive to gravity evaluations because of the elevation contrast between the valley basements and adjacent mountains, and the density differences between the Paleozoic rocks, the Tertiary volcanics, and the unconsolidated Quaternary sediments. Density values for rocks in the study area range from 2.6 to 2.7 g/cc for the consolidated Paleozoic rocks, to less than 2.4 g/cc for the unconsolidated valley sediments, and as low as 1.7 g/cc for the pumiceous volcanic sediments.

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In general, the large gravity lows in the valleys and basins reflect low-density volcanic and sedimentary rocks overlying denser consolidated rocks. Faults and steeply dipping bedrock are represented as closely spaced contour lines, especially along valley margins. Local undulations in the contour patterns of the gravity data may indicate small subbasins or pediments (erosion surfaces) (Erwin 1980). The wide spacing of gravity survey stations, however, limited the map resolution.

West (1987) reports that the basement in the southern part of the Toano Draw Subbasin is 7000 to 9000 feet below the ground surface. The basin shallows northward to less than 5000 feet deep. In addition, he suggests that faults, probably having normal displacement, bound the valley on all sides. Erwin (1980) and West (1987) conclude that pediments extend into the basin from the range fronts along the west, east, and south margins of the basin. These pediments are truncated by the frontal faults. Small northeast-trending features in the gravity contours in the southern part of the valley near Deadman Creek, and to the north near the southern end of Twentyone Mile Draw (Erwin 1980), may be related to smaller subbasins.

3.2.1.2 Aeromagnetics. A regional aeromagnetic map of the Wells quadrangle at a scale of 1:250,000 (DOE 1979) defines some of the larger scale features in the study area. The resolution of the data is limited because the flight lines were widely spaced. The data suggest that the volcanic deposits in the northern end of the basin are magnetically low and probably felsic in composition. Also, two magnetic anomalies to the north and west of the basin may be intrusive bodies, possibly remnants of the volcanic sources for the area.

3.2.2 Surface Geophysical Data Collection

Two geophysical surveys were conducted in the Toano Draw Subbasin during the period July 11 to 18, 1988, to determine the more effective method of detecting the presence and extent of potential water-bearing aquifers. One survey consisted of 23 Time Domain Electromagnetic (TDEM)

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soundings at 21 locations. Most sites were located at proposed or existing well locations. The other survey consisted of two dipole-dipole resistivity-induced polarization lines totaling about 27,000 linear feet in length.

These two geophysical methods have been used by the petroleum and mining industries in Nevada for several years. TDEM soundings have been employed for deep basin exploration and have been used in Nevada to map limestone and volcanic units at intermediate depths. This method is also used to define aquifer thickness at individual sounding stations. Dipole-dipole resistivity provides a tool for mapping lateral variations in resistivity of materials such as clay and gravel. It can also define shallow subsurface variability of aquifer thickness and character. The data from these two surveys were interpreted using available regional gravity and aeromagnetic data, lithologic and geophysical logs from new WCC borings and as available from existing water and petroleum wells, and results of geologic mapping.

The TDEM method was determined to provide the most conclusive information regarding aquifer thickness and character. As a result, an additional survey, consisting of 77 TDEM soundings in the Toano Draw Subbasin (Figure 3-2) and 9 soundings in the adjacent Montello area of the Thousand Springs Basin, was conducted.

3.2.2.1 TDEM Soundings. TDEM soundings map vertical variations in resistivity beneath an array consisting of a large transmitter loop and a smaller receiver loop placed on the ground. Most transmitter loop sizes for this survey were 1000 feet per side, although a few loops were 500 feet per side. A current with a square waveform is pulsed through the transmitter loop and received by the smaller loop located at the center of the array. The receiver records decaying voltages at specified times after the pulse is turned off in the transmitter loop. The measured rate of decay at the receiver is proportional to the rate of decay of the vertical

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magnetic field inside the loop. This in turn is proportional to the resistive structure below the station. The depth of exploration is a function of loop size, frequency of signal, and ground resistivity. Generally, the maximum exploration depth is approximately one to two times the length of one side of the loop. Based on correlation of the TDEM data with available well logs, the depth of exploration for this survey was 500 to 1000 feet for most soundings.

TDEM sounding sites were placed near existing or proposed wells and selected geographic features. Sounding locations were also selected where they were expected to provide the best information for constructing basin cross sections.

3.2.2.2 Dipole-Dipole Resistivity Mapping. Dipole-dipole resistivity surveys provide a combination of profiling (detection of lateral resistivity changes) and sounding (detection of vertical resistivity changes) to a depth of about 1000 feet. Two dipole-dipole surveys were conducted within the Toano Draw Subbasin. The basic array consists of two dipoles, a transmitter, and a receiver. Each dipole is 500 feet long and both dipoles are oriented along the same line. The dipoles are separated by varying distances equal to a multiple of the dipole length, e.g., 500, 1000, 1500, and 2000 feet. The array is moved along the profile line with each dipole acting alternately as a transmitter and as a receiver. High voltage current is applied to the transmitting dipole and a voltage is detected along the receiver dipole. The received voltage is interpreted as a resistivity value representative of the mean resistivity of the material between the dipoles. The mean values are plotted along the profile to create a cross section of resistivity values representing lateral and vertical changes.

3.2.2.3 Induced Polarization. Induced Polarization (IP) was initially considered as a possible method to evaluate aquifer potential. Investigations performed in similar conditions have reported that clays

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often have a unique IP response which distinguishes them from other materials. Preliminary evaluation of the IP data indicates that a condition referred to as inductive coupling exists at the site. This condition "masks" the clay responses and reduces the effectiveness of the IP survey. Thus, it was decided that the IP survey would not provide useful information for this study.

3.2.3 Borehole Geophysical Data

Geophysical logging is routinely conducted during development of oil and gas wells and also many water wells. The various logging methods provide additional descriptive tools beyond lithologic logging. Typically, several methods are used in a single borehole to insure that as much information is retrieved as possible. The most often used methods include:

- Long and short normal resistivity - these two methods measure the resistivity of materials at the borehole interface. The long normal method employs an electrode separation of 64 inches which allows it to detect material resistivities deeper into the boring wall. The short normal method uses an electrode separation of 16 inches which decreases the detection distance within the borehole but allows for increased vertical resolution of layers. Highly resistive units generally reflect coarse-grained materials. Lower resistivity values are typically associated with highly conductive clay units.

- Self Potential (SP) - this procedure measures the potential for current flow in a material. In a manner similar to normal resistivity, these intrinsic values can be used to map different units such as clays and gravels. In addition, SP can also be used to detect changes in water quality.

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- Natural gamma - clay materials generally contain relatively high percentages of Potassium. As Potassium-40 decays to Argon-40 it emits gamma rays. The natural gamma ray method detects the emission of these rays. A clay-rich unit, which may act as an aquitard, will be associated with higher gamma ray values than a gravelly unit.

- Caliper - calipers measure the diameter of the boring wall. Poorly consolidated gravelly materials tend to slough which results in an increased hole diameter. Clays, however, either retain the original dimension of the hole or, in the case of expansion clays, decrease the hole diameter.

3.2.3.1 WCC Monitoring Wells. The various downhole geophysical methods described in the previous section were utilized at the study site for select WCC monitoring wells. Strata Data, Elko, Nevada was contracted to conduct downhole geophysical surveys on the selected wells. The results of the surveys were used to interpret the TDEM data and are discussed in Appendix A-2, Correlation of TDEM Data with WCC Monitoring Wells.

3.2.3.2 Existing Water and Oil Wells. Several existing agricultural well logs, provided by the Nevada State Engineer's office, were used to confirm the interpretation of the TDEM data. In addition, an isopach map of the principal aquifer unit was constructed using selected well and TDEM data (Figure 3-3). Production records from Wells 41-65-35ab and 41-65-35bd show relatively high yields. These wells are located within the coarse-grained unit defined by the geophysical data. Toano Well No. 1, Toano Well No. 2, and Fivemile Draw Well lie near the margin of the proposed aquifer unit. These active stock wells have moderate to low production.

In addition, wells drilled in primarily fine-grained material and with poor production histories generally lie outside the coarse-grained unit defined by the TDEM data. Examples include the small wellfield west of WCC

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Well MW-2 and the Toilet and Jog Wells at the southern end of Twentyone Mile Draw (Figure 3-3 map of well locations and isopach).

Logs from three exploration oil wells were also used to refine the basin stratigraphy: Gulf Refining Company Thousand Springs No. 1 (T40N, R66E, sec. 8), Sun Exploration Company Southern Pacific No. 1 (T39N, R65E, sec. 33), Sun Exploration Company Southern Pacific No. 3-13 (T39N, R65E, sec. 13). Information from Sun Exploration and Production Company Toano Federal No. 1 (T40N, R65E, sec. 10), located in the area, was not used because only natural gamma logs, which do not provide much stratigraphic information, were available.

Thousand Springs No. 1 is located about 1 mile southeast of WCC Well MW-12 (EM-14). TDEM Sounding EM-47, located near the petroleum well, yielded stratigraphic information that was similar to the lithologic interpretation derived from electric and SP logs from the well.

Southern Pacific Wells No. 1 and No. 3-13 are located in the southwest portion of the basin. Logs from these wells provide the following information:

- Several hundred to thousands of feet of volcaniclastic sediments are present in both wells.

- Well SP No. 3-13 lies near the gravity low at the basin center. The upper 800 feet of section in this well is described as valley fill, probably the equivalent to the channelized alluvial units described in this report.

- An minimum slip of 8800 feet down-to-the-east can be estimated for a fault lying between the two wells. The upper, probably eroded, contact of Triassic marine sediments is located at a depth of 1615 feet in SP No. 1 and 10,422 feet in SP No. 3-13. No direct

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correlation of stratigraphic units could be made so the displacement estimate is a minimum value.

3.3 GEOPHYSICAL MODELING AND RESULTS

3.3.1 TDEM Data Analysis and Modeling

The iterative inversion program used in this study, AARTI by INTERPEX Ltd. of Golden, Colorado, is based on ridge regression. The modeling process begins with a seed model, usually consisting of three or four layers of specified resistivities and thicknesses. The program generates a forward solution of the voltage decay curve based on the seed model. The model and field data curve are then compared and through iterations an approximate match of the curves is developed. The number of layers and layer parameters (thickness and resistivity) can be changed, as required to improve the match between the model and the field data curve. The final result is an approximation of the layering of materials beneath the sounding site.

3.3.1.1 Correlation of TDEM Data. Data from other sources were used to correlate the TDEM data and the site specific number, thickness and lithologies of layers. These sources of data include lithologic logs from wells, geophysical logs from wells, production records from wells, and geologic mapping. The TDEM data were in reasonably good agreement with the applicable lithologic logs (see Appendix A-2 for detailed discussions of correlations). In general, wells located in areas suggested by the TDEM results to consist of large amounts of coarse material intersected thick sections of sand and gravel. It is noted, however, that the well logs did list some clay layers up to 20 feet thick that were not identified by the TDEM model.

Downhole geophysical logging, including short and long resistivity, spontaneous potential, natural gamma, temperature, sonic and caliper methods, was conducted in the well boreholes. Of these methods, the

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downhole resistivity logs provided the best correlation with the TDEM resistivities and were ultimately used, in conjunction with lithologic logs, to infer lithologies based on TDEM values.

Stratigraphic units described from geologic mapping were compared to results of the TDEM survey. Major lateral changes in TDEM resistivity values correspond to lithologic changes mapped at the ground surface. In addition, several faults mapped by geologic reconnaissance were also identified by TDEM methods.

3.3.1.2 Limitations. Several factors associated with the geophysical modeling can affect the results. First, the principle of equivalence states that for any given set of field data, such as the decay curve obtained at a TDEM sounding site, several different layered models may be applied equally well. This means that the geophysicist has to use judgement in deciding the number and thicknesses of layers which are most likely present at the site. This problem can be minimized by integrating other hydrogeologic information into the model.

Also, the TDEM model considers materials at a sounding site to consist of discrete, homogeneous layers. Actual conditions are usually highly variable and materials are heterogeneous. This limitation in the model may be minimized by correlation of sounding data with lithologic and electric well log records.

It should be noted that although TDEM soundings may provide a general indication of the thickness and distribution of coarse- and fine-grained deposits, the TDEM method alone does not have the capability to define the hydraulic properties of the material. However, it may be used in a general way, as an exploration tool to indicate the water-bearing potential of the unconsolidated sediments. Based on the available data in the Subbasin, it appears that TDEM provides better information regarding areas to avoid due to poor aquifer potential rather than pinpointing areas of promising production.

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3.3.2 Dipole-Dipole Resistivity Analysis and Modeling

Dipole-dipole resistivity data were processed in the field using a Zonge Engineering TIP-16 receiver. A resistivity and induced polarization value is computed for each station. The apparent resistivity value is computed as a function of the dipole spacing, the input transmitter current, and the measured receiver voltage. The induced polarization value is computed by a complex algorithm which compares the waveform detected by the receiver with the transmitter input waveform. These values are plotted onto a pseudo-section.

3.3.3 Toano Draw and Vicinity Results

3.3.3.1 TDEM Survey. The TDEM soundings may be used to establish a range of resistivities applicable to specific geologic materials. These resistivity values are then verified using data from electric and lithologic logs. In Table 3-1, the resistivity ranges considered applicable to the various geologic materials in the Toano Draw Subbasin are presented. The TDEM survey, utilizing these derived resistivities, defines the depth of the contact between a resistor overlying a conductor. Two such contacts were located during this study in the Toano Draw Subbasin. They are:

- The interface between the coarse-grained aquifer unit (15-30 ohm-m) and a clay rich unit (8-15 ohm-m)
- The contact between the clay-rich unit (8-15 ohm-m) overlying a clay-rich tuffaceous volcanic unit (< 8 ohm-m)

As a result of the limited resolution of the TDEM model, these contacts may actually be gradational and represent an interval 100 to 200 feet thick.

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Several cross sections of Toano Draw and vicinity were developed using the TDEM data (Appendix A-1). Profiles I through VIII trend east-west across the axis of the basin, and Profiles IX through XI parallel the Toano Draw drainage. Discussions of the individual profiles are included in Appendix A-1.

The TDEM survey and geologic mapping indicate that the coarse-grained aquifer occupies a relatively narrow but thick zone near the axis of Toano Draw. In the subsurface, this zone extends to the east and west of the present surface expression of the drainage (Figure 3-3). A relatively wide range of resistivity values has been assigned to this coarse-grained unit. This reflects the heterogeneity of the unit caused, in part, by local interfingering of finer-grained alluvial fan deposits.

In general, the three alluvial stratigraphic units defined by the TDEM model are all present near the axis of the basin. However, the upper two units thin and are commonly absent near the valley margins, where finer-grained deposits are more prevalent.

The configuration of sediments in this basin is not typical of the majority of basins in the Basin and Range province. More commonly, fine-grained sediments predominate at the center of the valley and coarse-grained sediments make up the majority of deposits along the range front. This difference in stratigraphy might be the result of several factors:

- Pluvial lakes, which deposit primarily fine-grained materials, have not extensively occupied the Toano Draw subbasin.

- Toano Draw is relatively narrow, allowing alluvial fans to extend farther into the center of the valley as compared to wider valleys. The fans have constrained the course of Toano Draw to the valley axis.

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- Unlike many valleys in the Basin and Range province, Toano Draw has an external drainage into Thousand Springs Creek. Fine-grained materials are washed out of the valley by the streams, leaving the coarser fraction behind.

3.3.3.2 Dipole-Dipole Resistivity Survey. The dipole-dipole survey was conducted in the southern part of Toano Draw, primarily between Toano Wells No. 1 and No. 2 (Figure 3-2). Apparent resistivities vary between 10 and 40 ohm-meters along the profiles. In addition, resistivity values generally decrease with depth. Higher resistivities are considered indicative of zones of sand and gravel while lower resistivities are associated with clay-rich layers. A thick, highly resistive section is located between Stations 110 and 125 on Line No. 1 (Figure 3-2), thus indicating this site may be favorable for water production. Well MW-15, drilled to a depth of 425 feet within this section, encountered 125 feet of gravel and sand at a depth of 275 feet. This was overlain by gravelly and sandy clay to the ground surface.

WCC Well MW-3, located at Station 22.5, is situated on the edge of a resistive unit. The upper 740 feet of this well is primarily coarse sand and gravel. Toano Well No. 2, a stock well, is located on a resistive feature with similar characteristics to that at Station 22.5. Both wells have relatively low yields which may be due to the proximity of the margin of the resistive unit.

3.3.4 Montello Valley

TDEM soundings were conducted in Montello Valley along a reconnaissance survey profile. Results of these soundings reveal a relatively thick section of material with resistivities from 24 to 31 ohm-meters. These resistivity values have been evaluated in conjunction with other lines of evidence suggesting that coarse-grained sediments of relatively high water transmitting capacity are present along this profile. This evidence includes:

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- Relatively high water production rates from large-capacity wells in Montello Valley.

- Well logs of existing water wells show thick sections of coarse-grained materials.

- Gravity data suggest that a thick section of sedimentary material (>9000 feet) exists in the area.

The TDEM data suggest that the bottom of the coarse-grained unit overlies low resistivity materials, most likely associated with volcaniclastic clays. Alluvial clays (8-15 ohm-meters) are indicated as being present at the southeast end and as a small wedge near the northeast end of the profile. A disparity in the apparent depth to bedrock between soundings EM-69 and EM-68 might be due to faulting.

3.4 STRATIGRAPHIC CHARACTERISTICS

Generalized stratigraphic descriptions of the rocks within the Toano Draw Subbasin have been written during previous hydrogeologic studies (William F. Guyton Associates, Inc. [Guyton] 1982; Rush 1968). Guyton divided the geologic units into three major categories based chiefly on anticipated water bearing capacities. The units, listed by increasing groundwater productivity, are noncarbonate consolidated formations comprised of Precambrian to Tertiary metamorphic rocks, shales, quartzites, granitic intrusives and volcanic rocks; carbonate rocks composed of Cambrian to Permian age limestone, lesser dolomite, and minor interbedded sandstone and shale; and unconsolidated sediments including lake deposits, tuffaceous sedimentary rocks, older alluvium, and recent alluvium.

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In this study, the geologic deposits are divided into five general stratigraphic units (Figure 3-4). This departure from the categories described in Guyton (1982) reflects the need to further define the water bearing properties of the materials. These units, in order of increasing age, are Holocene channelized alluvium, Pleistocene and late Tertiary channelized alluvium, Pleistocene and late Tertiary alluvial fan deposits, middle to late Tertiary volcanic rocks and volcaniclastic sediments, and Paleozoic and early Mesozoic carbonate and noncarbonate sediments and intrusive rocks. The Holocene channelized alluvial deposits, while not mappable at the scale of the geologic map (Figure 3-1), were considered important as a stratigraphic unit. They are represented on the map as lying within the Quaternary and Tertiary channelized alluvial unit. The ability of these groundwater units to transmit groundwater varies with their permeability.

Generalized cross sections across the width of the Toano Draw Subbasin (Figure 3-5 to 3-7) and along the trend of Toano Draw (Figure 3-8) were constructed using selected well data, TDEM profiles, and surface geologic mapping data.

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3.4.1 Holocene Channelized Alluvium

The youngest sediments within the Toano Draw Subbasin are composed primarily of channelized, unconsolidated alluvium. These deposits are located within the central portions of the larger channel systems such as Toano Draw, Five Mile Draw, Twentyone Mile Draw, and Thousand Springs Creek. They are also found within the numerous small, shallow tributary channels that drain into Toano Draw from the mountains and hills to the east, south, and west. These deposits have not been shown on the geologic map (Figure 3-1) because the scale of the map is too small to adequately represent them. The sediments are poorly to moderately sorted, coarse gravels and cobbles to sand, silt, and clay. They are derived from the older Tertiary and Quaternary alluvium, Tertiary volcanic rocks and sediments, and Paleozoic and Mesozoic rocks. In general, the alluvium is

confined to the present stream channel and is no more than a few hundred feet wide along the larger streams but only several tens of feet wide along the reaches of the smaller tributaries. Within the wider channels, such as Toano Draw, narrow, complex meanders exist within a broad floodplain. These smaller channels have incised into and reworked older Quaternary alluvium which makes up a large portion of the floodplain. The recent alluvium also exists as a thin veneer of overbank silt and sand along the margins of the channels. The thickness of these deposits varies as a function of channel width and length; the narrower, shorter channels contain Holocene alluvium only tens of feet thick while the larger stream channels have recent alluvium up to 100 feet thick.

The Holocene alluvial deposits are relatively well-sorted, coarse-grained, and permeable. Thus these deposits are more conducive to groundwater production. However, their limited thickness and the lateral extent of these sediments minimize their potential as a viable water supply.

3.4.2 Pleistocene and Late Tertiary Channelized Alluvium

Older alluvial deposits in the Toano Draw Subbasin occur as channel fill, gravel bars, and terrace remnants. These deposits are commonly overlain and incised by Holocene alluvium. They are composed primarily of detritus from Paleozoic and Mesozoic strata and Tertiary volcanic rocks and volcaniclastic deposits. The pre-Cenozoic lithologies range from limestone and dolomite to sandstone and mudstone. Volcanic clasts include rhyolite and andesite to basaltic composition. The oldest alluvium of this unit may have been deposited prior to Tertiary volcanism in the area. This may explain the virtual absence of volcanic clasts in a limestone-rich gravel bar exposed along the western margin of Toano Draw (Winecup Ranch, Nev. 7.5' topo. T40N, R65E, Sec. 5). Minor pluvial lakes most certainly occupied the lower elevations of the Subbasin in late Tertiary and Pleistocene time. The associated deposits consist of coarse beach gravels and sands along the lake margins grading to fine sands to clay toward the

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valley center. These sediments have been located in borrow pit exposures as thin (less than 3 feet) interbeds within the alluvial deposits. It is also possible that Thousand Springs Creek was blocked by large volumes of volcaniclastic debris during eruptive periods. The debris dams would form lakes which would deposit similar sediments to those associated with pluviations.

The composition of the Pleistocene and Tertiary channelized alluvial unit is similar to the Holocene alluvial unit. It consists of poorly to moderately sorted cobble and gravel to sands, silts, and clays. The degree of cementation is greater than that of the younger unit. These deposits may occur as layered successions of fluvial and pluvial subunits.

The subaerial extent of these deposits has not been clearly defined because the lateral contacts with adjacent alluvial fans are complex. Both the channelized alluvium and the adjacent fans were being deposited at the same time. Small variations in climate would allow one type of deposit to dominate the other. When the alluvial fans that presently form the extensive bajada along the adjacent range fronts were smaller, the channel of Toano Draw was wider than at present. However, at other times, the prograding fans confined the channel and limited its lateral extent. Thus, the lateral boundaries of this unit are diffuse as a result of interfingering with the alluvial fans and debris flows along its flank. The present surface exposure of this unit that is restricted in the center of the valley does not represent its full extent because it has been buried by alluvial fans and debris flows. Along the valley flanks it has been buried beneath Tertiary volcaniclastic sediments and Tertiary-Quaternary alluvial fans.

Geophysical mapping using Time Domain Electromagnetic soundings (TDEM) has provided approximate bounds for this unit. The depth to the base of the unit varies along the trend of Toano Draw; however, it does attain thicknesses estimated to be greater than 800 feet. Laterally, the unit is

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more difficult to define because of the diffuse nature of the boundary. It has been estimated from TDEM soundings that at the approximate latitude of Twentyone Mile Draw the unit could be up to 9 miles wide. However, the TDEM results also indicate that the unit is not homogeneous and could be highly variable in composition especially away from the center of the valley.

The alluvium thickness decreases sharply in the reaches of Thousand Springs Creek and Twentyone Mile Draw where pre-Cenozoic consolidated rocks closely bound the channel. The stream channel is less than 700 feet wide on Thousand Springs Creek southeast of Eccles Ranch. It is even narrower along Twentyone Mile Draw 6 miles south of Twentyone Mile Dam. No major faults or folds which may cause deep incision have been observed along these reaches. Alluvial thicknesses of 150 feet or less might be expected in these areas.

3.4.3 Pleistocene and Late Tertiary Alluvial Fan Deposits

Coalescing alluvial fans form the extensive bajada that occupies the majority of the surface of Toano Draw. Along the upper reaches of the fans, they are in faulted contact with Tertiary volcanic rocks and volcaniclastic sediments. They extend valleyward where they bound the Toano Draw channel for its entire length. Clasts are primarily derived from the volcaniclastic rocks and consist of rhyolite, andesite, and minor basalt compositions. The fans are generally poorly sorted except along established drainages. Grain sizes vary from coarse gravel to fine silt and clay. The relatively fine-grained nature of the fan materials is due to the erodible nature of the volcanic unit.

These fans have a low, rounded relief characterized by numerous broad, shallow channels. These channels form nearly linear courses along the length of the fans and have virtually no integration with adjacent drainages. The majority of the channels head at the faulted contact with the volcaniclastic unit. Through-going drainages between the volcanics and

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the alluvial fans are infrequent. This may be due, in part, to the dip of the volcanic beds which opposes surface flow.

The thickness and subsurface lateral extent of the alluvial fans is variable. The fans interfinger with the Pleistocene and Tertiary channelized alluvium near the center of the valley. The overall thickness of the unit is probably greater than 1000 feet based on lithologic logs from petroleum exploration wells. This thickness can be attributed to the progressive downdropping of the valley along the frontal faults.

The alluvial fans do not appear to be good sources of groundwater. They are composed of relatively fine-grained clasts with considerable silt and clay in the matrix. Wells drilled in this unit (WCC Nos. 40-65-27 and 40-65-35) have produced relatively small quantities of water.

3.4.4 Tertiary Volcanic Rocks and Volcaniclastic Sediments

Volcanic rocks are exposed at the surface along both margins of Toano Draw, adjacent to the Paleozoic core of the mountains, and along the northern margin of the Subbasin (Figure 3-1). These rocks are composed primarily of acidic rocks such as rhyolites, andesites, and associated tuffaceous sediments. In addition, basaltic flows occur in the northern portion of the Subbasin. The volcanic rocks are expressed as low, undulating hills, between 6500 feet and 5900 feet in elevation, that have north-south trending crests. In the northeastern part of the study area, along Twentyone Mile Draw, the volcanic sediments dominate the topography along the lower elevations. They lap onto the flanks of the Paleozoic and early Mesozoic bedrock and fill the lowlands. It appears that these sediments have buried a more extensive previous drainage system.

Normal faults along the range fronts on both sides of Toano Draw have rotated the volcaniclastic units so that bedding dips steeply toward the mountains (greater than 60°) and away from the center of the valley. As a further consequence of faulting, volcanic rocks valleyward of the faults

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have been downdropped. Two fault splays mapped on the western side of the valley form the western and eastern contacts of the volcanic unit. Two petroleum exploratory wells drilled on the southwestern side of the valley by Sun Exploration Company penetrated these rocks. Well SP-1 (WCC No. 39-65-33cb) is located in Deadman Creek between the two faults. Lithologic logs suggest that the top of the volcanic rocks is at about 750 feet below the ground surface and the base is at 1700 feet. In contrast, Well SP 3-13 (WCC No. 39-65-13dd), located east of the range front faults, penetrated the top of the volcanic unit 1600 feet below the ground surface. The bottom of the unit is greater than 4500 feet deep. This concurs with analysis of TDEM soundings which suggests the volcanic rocks occur at a much greater depth on the downdropped side of the faults.

Permeabilities of the volcanic rocks vary. Welded tuffaceous units, which consist of a large component of glass, generally contain low effective porosities and are, therefore, of low permeability. Tuffaceous sandstones and vesicular rocks exhibit relatively large permeabilities and effective porosities. These welded and nonwelded units are closely associated within the volcanic unit and typically occur as sedimentary groups. Their individual thicknesses may range from tens of feet to several hundred feet. Therefore, some sections of this unit may be capable of carrying significant quantities of water.

The dip of bedding, away from the valley center, opposes the flow of surface and groundwater. Several drainages, such as Hunter's Draw, Deadman Creek, and Immigrant Creek, have established courses which drain from the higher elevations of the mountains into Toano Draw. Few other drainages transport water along the surface across the volcanics. It may be that a substantial quantity of the water draining from the higher mountain infiltrates into and is recharging the volcanic unit.

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3.4.5 Paleozoic and Early Mesozoic Carbonate and Noncarbonate Sediments and Igneous Intrusive Rocks

The oldest rocks in the study area are Paleozoic sediments that make up the cores of the Windemere Hills to the west, the Gamble Range to the east, and the Pequop Mountains to the south and form the basement beneath Toano Draw. The rocks range from Cambrian to Permian in age and are principally carbonate rocks such as limestone and lesser dolomite of the Pequop Formation (Hope and Coats 1976). Additional lithologies include mudstones, siltstones, and granitic intrusive rocks. A small erosional remnant of early Mesozoic marine sediments is located in the northern part of the Windemere Hills to the west of the Toano Draw Subbasin.

These rocks have been rotated by range bounding normal faults resulting in strata which dip between 20 and 45° away from Toano Draw. These rocks have been faulted to a substantial depth near the middle of the basin. Sun Exploration Company Well SP 3-13 (WCC No. 39-65-13dd) penetrated mudstone and limestone at a depth of 4500 feet in the southern portion of the valley.

The permeability of these rocks is not clearly understood. Numerous karst caverns and voids are visible in limestone outcrops on both sides of Toano Draw. Dissolution along fractures and faults within the limestone rocks is also common. However, the number and extent of possible water conduits has not been estimated. Some speculation has existed for some time as to the role the carbonate rocks might play in the storage and transmission of groundwater in this area of Nevada. Maxey (1968) postulated that areas in eastern Nevada having predominantly carbonate mountains and valley basements must contain appreciable amounts of water. Rush (1968) estimated that water flow rates between the Toano-Rock Springs area and the Montello-Crittenden Creek area may be between 6000 and 12,000 acre-feet/year.

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4.0
HYDROGEOLOGIC SETTING

4.1 HYDROSTRATIGRAPHY

For the purposes of this study, the stratigraphic units of importance for characterizing the groundwater flow system have been subdivided based on the general water-bearing properties of the units. The titles of the following subsections indicate the stratigraphic units of interest in this study.

4.1.1 Alluvial Aquifer

The relatively coarse-grained, unconsolidated alluvial channel deposits, which are present within the central portions of the valleys and along the ephemeral streams, comprise the alluvial aquifer. This aquifer is the principal groundwater bearing unit within the Toano Draw Subbasin, along the Thousand Springs Creek, and within the Montello Valley. It consists of a heterogeneous mixture of stream-deposited sand and gravel, with interbedded silt and clay deposits. The permeability of these alluvial channel deposits is related primarily to the grain size and degree of sorting of the grains during deposition. In general, the permeability is higher in the more well-sorted coarse-grained channel deposits. Typically, the deposits having a higher degree of sorting would occur in the central portion of such a basin because the streams depositing these sediments would have had relatively low gradients in this area as compared to the higher gradients of those stream reaches along the mountain front margins of the basin. The lithologic characteristics of this alluvium, which is Holocene (Recent) to Tertiary in age, are further described in

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Sections 3.4.1 and 3.4.2. The thickness and extent of this aquifer are described below in Section 4.2. The hydraulic characteristics of this aquifer are described in Section 4.6 below.

4.1.2 Alluvial Fan - Volcaniclastic Aquitard

The very fine-grained, alluvial fan, lake and volcaniclastic sediments that have been deposited along the mountain fronts, on the margins of the valleys, constitute the alluvial volcaniclastic aquitard. This aquitard consists of great thickness of silt and clay including significant amounts of volcanic ash. These fine-grained sediments occur adjacent to and extend beneath the alluvial aquifer unit in the Toano Draw Subbasin. This unit is not capable of yielding economically significant quantities of water to wells because of its low hydraulic conductivity (low permeability). However, on a large scale, this unit contains large volumes of water because of its high effective porosity. Also on a large scale this unit is capable of transmitting a significant amount of groundwater into the alluvial aquifer. The lithologic and stratigraphic characteristics of the aquitard, which consists of Quaternary alluvial fans and Tertiary Volcaniclastic Sediments, are further described in Section 3.4.3.

4.1.3 Paleozoic Carbonate Aquifer

Consolidated carbonate rock formations of Paleozoic Age are exposed in the mountain ranges that form the margins of the subbasins within the Thousand Springs Basin and it is believed that they are continuous between the ranges although covered by the alluvial valley infill materials. The extent, distribution, and hydraulic properties of these formations is not well-defined because of the great depth at which they occur beneath the Toano Draw Subbasin. However, significant secondary porosity features, including vugular and cavernous openings along fractures, have been observed in outcrops of these rocks along the northeastern margin of the Toano Draw Subbasin and in the Gamble Range. From observation of these features it may be inferred that this unit might have a high capacity for transmitting groundwater regionally, particularly along deep flow lines.

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This may account for deep groundwater movement out of the Toano Draw Subbasin as recognized by Rush (1968). Regional groundwater flow through these carbonate rocks has been discussed by Maxey (1968). In addition, Rush (1968) has noted that many areas of eastern Nevada are underlain by carbonate rocks that convey groundwater flow beneath and between valleys and supply water to large springs.

4.2 DEFINITION OF AQUIFER THICKNESS

The late Tertiary and Pleistocene channelized alluvium and Holocene channelized alluvium are the most likely shallow (less then 1000 feet) groundwater sources in Toano Draw. They consist of unconsolidated sediments that are porous and have relatively high permeabilities. The youngest unit, the Holocene channelized alluvium, is relatively unimportant as a potential source of groundwater because of its limited aerial extent and thickness. However, it must be considered part of the aquifer system because it incises or directly overlies the older alluvium in the central portion of the valley and along the major tributaries. The younger unit also attains its greatest thickness, about 50 feet and possibly as great as 100 feet, at these locations. In addition, both alluvial units possess similar lithologies. The older unit, however, has a higher degree of cementation. Because of the similarities and spatial relation of the two units they have been considered a single aquifer for this study.

Estimates of the alluvial aquifer thickness are based on data from water and petroleum well logs, geologic reconnaissance, and geophysical exploration. These data have been utilized to construct isopach maps of the aquifer (Figure 4-3). Significant features include an irregularly shaped, elongate form that trends northwest-southeast; the thickest portion of the aquifer is generally along the central axis of the Basin; its thickness varies from less than 50 feet near the margins of the Toano Draw Subbasin to greater than 800 feet near the center of the valley; it is bounded by faults to the east, west, and southeast; and irregularities in

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the configuration of the aquifer appear to be structurally controlled. A more detailed description of the aquifer from north to south follows.

In more detail, the aquifer is oriented generally along the central axis of Toano Draw. It trends north-northwest and has an irregular form which roughly conforms with the shape of the Toano Draw Subbasin. The width of the unit, based on TDEM and well log data, varies along the length of the valley. The width of the unit at several points from north to south is about 2 miles wide at the north, in the area between Thousand Springs Creek and Five Mile Draw; greater than 9 miles at about the latitude of the southern reach of Twentyone Mile Draw; less than 3 miles from just north of Toano Well No. 1 to slightly north of the confluence of Deadman Creek and Toano Draw; almost 9 miles along a narrow spur which coincides with Deadman Creek; and less than 4 miles wide south to Valley Pass, the drainage divide with Goshute Valley.

The above estimates of width of the aquifer are minimum values. Few data are available from the margins of the Basin because there are few wells around the margins and the area was not extensively covered during the TDEM survey. The resistivity values from the few TDEM sites located along the margins suggest that the aquifer is relatively thin, i.e., less than 50 feet thick. The TDEM data indicate that these materials are more fine-grained than the main body of the aquifer due to interfingering with tuffaceous sediments and alluvial fan deposits. The maximum width of the aquifer is controlled by the generally north-trending Basin and Range style normal faults that bound the valley near the range-fronts.

The prominent, wider sections of the aquifer are attributed to established drainages, cross-valley structures, or both. An example is the northeast-trending lobe coinciding with Deadman Creek in the southwest corner of the Basin. The drainage overlies a slight gravity low possibly caused by a fault or warp in the bedrock basement (Erwin 1980). The increased depth to basement caused by the structure is responsible for

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greater thicknesses of the deposits. Estimated thickness of the aquifer along this lobe exceeds 800 feet.

Another relatively large extension of the aquifer is located 3 miles east of the Winecup Ranch in the northeast portion of the valley. This north-trending feature is 4 miles long, about 2 miles wide, and estimated to be up to 800 feet thick. Aerial photograph analysis and surface reconnaissance show this feature to be an older gravel deposit, possibly related to the lower section of the late Tertiary and Pleistocene channelized alluvium unit. The gravel deposit is an erosional remnant forming a topographic high 20 to 30 feet above the surrounding broad, low alluvial fans. The gravels are bounded by north-trending normal faults which created a depositional Basin. This would account for the increased thickness of deposits at this location. A WCC monitoring well (MW-5) was drilled on the west side of a range front fault at the western end of the Deadman Creek lobe of the aquifer. This 290-foot-deep boring encountered only 170 feet of fine-grained alluvial fan material. This supports the interpretation that the frontal fault bounds the western end of the deeper part of this aquifer lobe.

The alluvial aquifer overlies Tertiary volcaniclastic sediments that have also been downdropped along the range front faults on both sides of the Basin. Sun Exploration Company Petroleum Well SP 3-13 (WCC No. 39-65-13dd), located in the southern portion of the valley, penetrated the top of the volcanics about 1600 feet below the ground surface. The lithologic logs indicate that the alluvial aquifer extends to almost 900 feet. A finer-grained siltstone section lies directly beneath the aquifer and above the volcanic unit. The base of the aquifer does not lie at a consistent depth throughout the valley. Gravity data suggest that the Basin is deepest in the southern third of the valley (Erwin 1980). This is roughly coincident with the thick section of aquifer mapped at approximately the confluence of Deadman Creek and Toano Draw. Another deep portion of the Basin occurs at the wider portion of the aquifer at the latitude of the

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southern extent of Twentyone Mile Draw. This thick section of material continues northward along the narrowed section of the aquifer to Thousand Springs Creek.

The thickest part of the aquifer does not coincide with the present course of the Toano Draw drainage channel in the northern half of the Subbasin. The thickest part instead lies 1 to 1.5 miles east of the surface drainage. Possible causes for this deviation from the present drainage course include more rapid progradation of alluvial fans on the east side of the valley relative to the west side, that forced Toano Draw to the west; tilting of the Toano Draw Subbasin toward the west by dominant normal faults along the Windemere Mountains; and natural migration of Toano Draw to the west. To the south the aquifer axis is believed to lie directly beneath the present drainage course. The valley is much narrower in this part of the Basin and confines the drainage more than in the north.

4.3 WELL AND SPRING INVENTORY

An inventory of wells and springs in the project vicinity was performed by WCC hydrogeologists in July and August 1988. Records of drillers' logs were researched at the Nevada State Engineers office in Carson City. Information regarding springs in the project area was provided by the Regional Office of the Bureau of Land Management in Elko. Groundwater level measurements for selected wells in the Toano Draw Subbasin were provided by the Elko field office of the United States Geological Survey.

The well and spring inventory was performed to:

- Summarize well ownership, well construction, pumping data, and groundwater use (Appendix I)

- Identify wells and springs to be sampled to characterize background water chemistry and provide information regarding groundwater origin and age (Section 5.0)

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- Obtain groundwater level measurements to develop a water table contour map, and assess groundwater flow direction and aquifer hydraulic gradient (Section 4.5)

- Supplement the knowledge of the distribution of aquifer materials (Sections 3.0 and 4.2 above)

- Identify wells and springs that may be affected by groundwater development in the project area (Section 10.0)

Information obtained from the agencies listed was used to develop a well and spring location map (Figure 4-1) and a detailed tabulation of data regarding well and spring characteristics (Appendix I). Information contained in the WCC well and spring inventory extends and expands the information provided on wells and springs by Guyton (1982) and Rush (1968).

A field reconnaissance of selected wells and springs was conducted by WCC hydrogeologists to confirm and update information gathered from the agencies and from the existing technical reports by previous investigators. Approximately 100 wells and 30 springs were visited. A description of the condition of each well and spring, and other pertinent information, was noted. If a well was being pumped, an estimate of discharge was made. Spring discharge was also estimated. Depth to water measurements were performed where possible. Photographs were taken of selected wells and springs.

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4.4 INSTALLATION OF MONITORING AND TEST WELLS

A total of seven monitoring wells and five test wells were drilled under the supervision of WCC hydrogeologists in the project vicinity. Three additional exploratory borings were drilled at proposed monitoring well locations but were not completed as wells because of the hydrogeologic

conditions encountered. Well locations and completion details are listed in Table 4-1. The method used to drill a particular well was dependent upon the purpose of the boring, formation characteristics, and sampling needs. Lithologic logs for each well were prepared from drill cutting samples as drilling progressed (Appendix E). A suite of borehole geophysical logs was also performed as described below. The three drilling methods used were air rotary, mud rotary, and cable tool.

4.4.1 Description of Air Rotary Drilling Methods

Air rotary drilling is identical to mud rotary drilling except that air is used to carry cuttings to the surface instead of mud. Compressed air is forced down the inside of the drill string, where it escapes from ports in the drill bit to transport cuttings to the ground surface. Injecting a small volume of water or surfactant decreases the amount of dust produced. Air drilling is useful for drilling through consolidated or semi-consolidated materials because of the generally rapid penetration rate and because it is possible to detect major changes in groundwater conditions while drilling. When loose, unstable formations are encountered, and where sticky clay formations are encountered at depths greater than about 400 feet, drilling mud must be used in the borehole. The rigs utilized by WCC on this project had the capability to drill with both air and mud. Test wells TW-1, TW-12, TW-14, TW-15 and monitoring wells MW-1, MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-12 were drilled using air rotary methods to the maximum possible depths and then, as conditions required, continued deeper using mud rotary methods.

4.4.2 Description of Mud Rotary Drilling Methods

For mud rotary drilling, the borehole is advanced by rotating a bit and removing cuttings by continuous circulation of a drilling mud. The bit is attached to the lower end of a string of drill pipe. A gasoline- or diesel-powered engine provides power to rotate the entire drill string. Drilling mud is pumped down through the drill string and ejected from ports or jets in the drill bit. Drill cuttings are carried in suspension by the

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drilling mud to the ground surface in the annulus between the borehole and the drill pipe. At the surface, the drilling fluid is channeled to a pit or tank where the solids are allowed to settle. Clean mud is then recirculated down the borehole. Formation samples can be obtained from the drilling mud stream as it discharges from the annulus. However, these samples may not be representative of the formation material at the drilling depth. Clay and silt may be separated from the formation material as it is carried in the mud stream. It is also difficult to accurately determine if a sample is truly from the depth at which the bit is working. Mixing of formation material from different intervals occurs as the cuttings are broken from the formation and when they appear at the ground surface. The rotary drilling method is most useful in that it allows for rapid drilling rates and deeper drilling depths.

4.4.3 Description of Cable Tool Drilling Methods

During drilling using the cable tool method, the borehole is advanced by repeatedly lifting and dropping a heavy string of drilling tools into the borehole. The drill bit or chisel breaks or crushes consolidated materials into small fragments, whereas the bit primarily loosens the material when drilling in unconsolidated formations. The crushed or loosened materials are mixed by the reciprocating action of the tools with added or formation water to form a sludge or slurry at the bottom of the borehole. When the crushing action of the tools is diminished by the accumulation of the slurry, the drill bit is removed from the borehole and the slurry is removed using a bailer.

Because the cable tool drilling method inherently does not disrupt the formation being drilled as much as rotary methods, formation samples obtained during cable tool drilling are representative of the actual formation materials at the depth from which the sample is obtained. For this reason, test well TW-3 was drilled using the cable tool method. Samples were obtained from this well at 10-foot intervals from a 178-foot depth to a total depth of 408 feet. Petrographic analyses were performed

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by Core Laboratories of Irving, Texas on samples from selected depth intervals. Analytical methods and results are summarized in Appendix H.

The cable tool method was used to drill monitoring wells MW-16 and MW-17 in November 1988 and January 1989. Because drilling muds are not needed with this method, subfreezing temperatures did not present major problems. Additionally, the mechanical operation and maintanance of a cable tool rig, as compared with a rotary drill rig, is much easier and less problematic during subfreezing weather.

4.4.4 Borehole Geophysical Logging

Geophysical logging was conducted immediately after the drilling of each borehole. Temperature, caliper, spontaneous potential, natural gamma ray, acoustic (sonic), and short and long normal resistivity logs were run in each borehole. The techniques of borehole geophysical logging are further discussed in Section 3.2.3. Reproductions of each log are presented in Appendix D.

4.4.5 Test Well and Monitoring Well Installation

After determining the appropriate well completion intervals and depths from the results of geophysical logging, installation of casing and well screen commenced. If necessary, the bottom of the borehole was backfilled to the level where well completion was to start with a low-permeability seal consisting of a mixture of bentonite and gravel. An additional seal of pure bentonite was placed at the base of the completion depth interval. The well screen was set in the completion interval adjacent to coarse-grained aquifer material, lowered on casing that was installed in the borehole to ground surface. A filter pack consisting of clean silica sand and gravel was then placed in the annulus of the borehole between the casing and well screen and borehole wall. A bentonite seal was set above the filter pack. Cement grout was poured into the borehole to ground surface and a length of protective steel pipe with a lockable cap was installed to protect the well.

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4.4.6 Test Well and Monitoring Well Development

All wells were developed after an appropriate time had elapsed to allow cement and grout to set. Development is necessary to remove fine-grained sediment from the formation surrounding the well screen and to facilitate the movement of groundwater into the well bore.

All monitoring wells and test wells, with the exception of test well TW-3, were developed by air-lift pumping. An air line and eductor pipe were placed in the well extending to the screened interval. Water was ejected from the well by compressed air supplied by the rig compressor. Fine-grained sediment was removed from the surrounding formation material by the movement of water into the wellbore and was expelled as air-lift pumping progressed. Pumping was periodically ceased and then resumed to allow for water movement into and out of the formation. This agitation facilitates removal of fine-grained sediment from the filter pack. Development was considered complete when water produced from the well contained insignificant amounts of sand and was no longer turbid.

Test well TW-3 was developed by a combination of surging, bailing, and pumping using a diesel-powered vertical line-shaft turbine pump. These methods were used because the large diameter of the casing and greater volume of fine-grained sediment expected excluded the use of air-lift pumping. Surging was accomplished by inducing flow into and out of the well screen by the use of a surge block. The surge block was moved up and down the inside of the screened sections of the well in a vigorous reciprocating action. As sediment was removed from the formation it settled at the bottom of the well were it was removed by bailing. This action was repeated along all sections of well screen several times. When development by surging and bailing had continued sufficiently, a diesel powered vertical line-shaft turbine pump was installed in the well. The well was then pumped at rates substantially greater than its sustainable yield. When drawdown in the well reached the pump intake, pumping was

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ceased and water allowed to run back into the well from the pump column. This created flow into the formation, minimizing bridging of sediment. TW-3 was developed until the water discharged did not contain sand and was not turbid.

4.5 GROUNDWATER FLOW SYSTEM

This section describes the available measurements of groundwater levels in the context of defining hydraulic head distribution and inferring flow directions within the groundwater flow system. First, a brief discussion of the scale and components of flow systems. A groundwater flow system within a basin may be described, following the concepts of Toth (1963), Maxey (1968), and Freeze and Witherspoon (1966), as consisting of three areas or zones. These areas of a basin are listed below, in order of decreasing topographic elevation.

1. A recharge area where the movement of water is primarily downward
2. A zone of prodominately lateral flow
3. A discharge area where the movement of water is primarily upward

Groundwater flow systems may also be defined on three different scales: regional, intermediate, and local. Flow path length and depth increase with the increasing areal scale of the flow system. Recharge areas for these regional systems lie within the mountainous areas having the highest topographic elevation present within the regional watershed. Discharge areas for regional flow systems are in the topographically depressed areas (lower elevations) of the same large-scale watershed in which the recharge zone flow lines originate. Typically, the springs that are regional discharge points have large flow rates, relatively high temperature, and little seasonal fluctuation in flow rate (Maxey 1968).

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Local groundwater systems are characterized by short flow paths. Local flow systems typically underlie small watersheds and contain flow lines that extend only to shallow depths. These local flow systems typically have spring discharge points with water of relatively low temperature and large seasonal fluctuations in flow rate (Maxey 1968).

In the area of this study, the regional groundwater flow system extends from a recharge area in the Snake Mountains, on the west of the Thousand Springs Basin, to the discharge area that is within the Montello Valley and points further east. Several flow systems of intermediate scale, such as the flow system of the Toano Draw Subbasin, are superimposed on this regional flow system.

Examples of local flow systems include those underlying the watersheds of the Deadman Creek, Hunter Draw, and Immigrant Creek. The boundaries of, and flow directions within, these flow systems have been characterized in this study, with emphasis on the Toano Draw Subbasin based on several lines of hydrogeological evidence. These include the analysis of groundwater level data, distribution of hydraulic head data, and the configuration of the water table, as described below.

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4.5.1 Groundwater Level Data

Water level measurements were collected by WCC during August 1988 through February 1989, in 41 existing wells, 2 existing piezometers (installed by WCC in 1982), and 12 monitoring wells and test wells installed by WCC during Summer and Fall 1988. These groundwater level measurements are provided in the detailed tabulation of well and spring characteristics included in Appendix I. These data are supplemented by well measurements provided by the U.S. Geological Survey (open file data), Guyton (1982), Gabbay (1987), and Rush (1964).

The available groundwater level data within and in the vicinity of the Toano Draw Subbasin, that are assumed to represent the water table, show a close correlation with the ground surface topogaphy (Figure 4-4). From this correlation it may be inferred that the water table is closely related to the ground surface. Establishing this relationship provided a basis for interpolating and extrapolating the available water level data to areas where no water level data were available (i.e., no wells were present for making measurements and no springs existed which constituted a surface expression of the water table).

4.5.2 Water Table Configuration

The elevation and configuration of the water table was mapped in the areas of the Toano Draw Subbasin, Thousand Springs Creek, and Montello Valley (Figure 4-5). This water table contour map was prepared using the available water level measurements described in Section 4.5.1 above. Only the measurements that were judged to approximately represent static (non-pumping) water table conditions were used in constructing this map.

The water table surface conforms to topography and drainage basin morphology (Figure 4-5). Groundwater divides are present beneath topographic divides. That is, in areas underlying topographic ridges, the water table is elevated with and reflective of the topography. Conversely, the water table forms trough-like depressions, reflecting topography, in areas underlying the valleys.

This water table contour map illustrates the approximate direction and magnitude of the groundwater hydraulic gradients. The contours represent the approximate areal configuration of the water table, not the vertical components of the hydraulic gradient. However, it may be inferred that the hydraulic gradient is approximately perpendicular to the contours, in the direction of decreasing elevation. The contours on this map represent lines of equal hydraulic head at depths near the water table surface. Thus the change in elevation of the water table indicated by the water table

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contours, for a given distance in the direction perpendicular to the contours, represents the approximate magnitude of the hydraulic gradient.

Hydraulic gradients, as indicated by contour spacing on Figure 4-5, are generally steeper in the topographically elevated areas surrounding the Toano Draw Subbasin, Thousand Springs Creek, and Montello Valley. In the central portion of the Toano Draw Subbasin, and similarly along Thousand Springs Creek and in Montello Valley, the hydraulic gradients are relatively much smaller in magnitude. From this observation, assuming constant groundwater flux through the flow system as a whole on a large scale and under steady-state conditions, it may be inferred that the areas of relatively low hydraulic gradient (i.e., widely spaced water table contours) are the areas underlain by portions of the aquifer that have relatively high transmissivities (i.e., thicker and/or more permeable aquifer materials). Considering that the flow paths converge from the margins of the valley to an area in the center of the valley where the hydraulic gradients are lower is also indicative of the presence of an aquifer of higher water transmitting capacity in the center of this subbasin. This inference is consistent with other lines of evidence that indicate higher aquifer transmissivities in the central portions of the basins, such as geological mapping (Section 3.1), results of geophysical surveys (Section 3.3), and the geological definition of aquifer thickness (Section 4.2).

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4.5.3 Groundwater Flow Directions

Groundwater flows, as a result of the hydraulic gradient, through sediment and rocks containing sufficient effective porosity to provide a continuum for flow. That is, groundwater flows from areas of higher hydraulic head to areas of lower hydraulic head. On a large scale, it is reasonable to assume that geologic units that provide the framework for a hydrologic flow system are homogeneous and isotropic (Maxey 1968). Thus by inference from the configuration of water table contours (Figure 4-5), groundwater flows generally away from topographically elevated areas and converges toward topographic valleys and depressions.

In the Toano Draw Subbasin, flow is generally toward Toano Draw from the Pequop Mountains, Windemere Hills, and the Gamble Range. In the central portion of Toano Draw the flow direction is generally northward. The water table contours shown on Figure 4-5 are judged to represent the intermediate-scale flow system of the Toano Draw Subbasin. Of course, where surface topography has created local flow systems, on a small scale the flow directions may be substantially different from those represented by the intermediate scale system that was mapped. For example, on the northern side of the Canyons of Hunter Draw at Deadman Creek, the small scale flow directions would be southward, in general accord with the topographic slope. Within the larger-scale Toano Draw flow system, it is reasonable to assume that there is a significant downward component of flow in the topographically elevated areas surrounding the Subbasin and an upward component of flow in the topographically depressed areas in the northern end of the Subbasin near Thousand Springs Creek. This description of the flow system is consistent with the model described by Maxey (1968) and Toth (1963). It is also consistent with the increased hydraulic head observed with increasing depth in the MW-1 boring, which is located near the confluence of Toano Draw and Thousand Springs Creek.

On a regional scale, the groundwater flow directions are influenced by the large scale topographic relief. Flow paths in the regional flow system of the Thousand Springs Basin probably originate in the higher elevations of the Snake mountains and Pequop mountains, west and south, respectively, of the Thousand Springs Basin, following the model described by Maxey (1968) and Toth (1963). In these recharge areas flowlines would have a steep downward component. Areally, flow would be generally eastward toward the lower-elevation discharge areas lying in the eastern Montello Valley and points further east in the Great Salt Lake Basin. In these discharge areas there is a significant upward component in the flow paths, as evidenced by the deep wells which have been observed to flow under artesian conditions in the Montello area.

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4.6 HYDRAULIC CHARACTERISTICS

The hydraulic characteristics of unconsolidated sediments in the Toano Draw Subbasin were estimated from the results of six constant rate aquifer pumping tests performed at test well locations TW-1, TW-3, TW-12, TW-14, TW-15, and the pre-existing irrigation well 41-65-35ad (Figure 4-1). Duration of five of the tests ranged from 8 hours to 48 hours each. The long-term test conducted in well 41-65-35ad, which is located approximately 100 feet east of well MW-17, had a pumping duration of approximately 14 days. The hydraulic characteristics estimated from these aquifer tests include transmissivity, hydraulic conductivity, and storage coefficient. These data were used in conjunction with aquifer test data reported by others, as input to the groundwater flow model, which in turn was used in evaluating the groundwater resource and drawdown effects of pumping to supply the power plant.

In addition, an empirical relationship was developed between specific capacity and transmissivity based on the tests performed by WCC and data reported by Guyton (1982). This correlation will enable estimates of transmissivity to be made where only specific capacity data, based on short-term tests performed in previous investigations, are available.

4.6.1 Aquifer Testing Approach and Procedures

The test well locations were selected to provide a wide spatial distribution of aquifer hydraulic data within the Toano Draw Subbasin (Figure 4-1). MW-series monitoring wells were installed within 100 feet of test wells TW-1, TW-3, TW-12, and well 41-65-35ad to enable collection of additional water level data during the aquifer tests.

The aquifer tests were conducted using the methods and instrumentation summarized below. Details of the standard operation procedures (SOP) are provided in Appendix F.

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Prior to conducting each test, water levels were monitored in the test well and observation wells, as applicable, to observe that the water levels were fully recovered from the previous well development activities. Prior to the testing, a short period of trial pumping at various rates was performed at each test well to identify an appropriate pumping rate for each aquifer test. The final pumping rate was selected based on the pump capacity, the depth to the pump intake, and the amount of drawdown at selected (stepped) pumping rates. For each constant rate test, the maximum sustainable pumping rate was selected, given the limitations of well casing diameter, lift, and pump capacity. Water levels in all monitoring wells and test wells were allowed to fully recover to static conditions prior to initiation of each constant rate pumping test. Each of the aquifer tests was conducted by pumping at a constant flow rate (Q) throughout the test.

Water level data were recorded for each test using both a programmable datalogger (In-Situ) and a manually operated water level indicator (Solinst). The pressure transducers used with the datalogger were installed in both the test well and the observation well. Manual water level measurements were made and recorded frequently in both the well being pumped and during both the pumping and recovery phases of each test.

4.6.2 Data Analysis Methods

The methods used to analyze the aquifer test data were selected based on the characteristics of the data and the hydrogeologic setting of the well location. The methods used were the Cooper-Jacob modified non-equilibrium analysis method (Cooper and Jacob 1946 and Driscoll 1986) for both drawdown and recovery data. Drawdown and recovery plots for each test, including analysis of the data, are shown on Figures 4-6 through 4-18.

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Water level responses measured in the pumping well and observation well, as applicable, were analyzed. The aquifer hydraulic prperties were evaluated using the drawdown data from the portion of the test that was judged to be most representative of the aquifer within the zone of influence of the test well. In all cases, borehole storage effects were apparent in the early-time data and, therefore, early-time data were excluded from the analysis to avoid misinterpreting the hydraulic response of the aquifer.

4.6.3 Hydraulic Properties

The values of transmissivity, hydraulic conductivity, and storage coefficient, estimated from the aquifer tests, are summarized in Table 4-2. Transmissivity values range from approximately 2000 gallons per day per foot (gpd/ft) to 50,000 gpd/ft. The lowest transmissivity was observed at the TW-3 well location and the highest transmissivities were observed at well TW-15 and well 41-65-35ad. This wide range of values reflects the locally variable hydraulic properties of the heterogeneous unconsolidated sediments in Toano Draw. In an environment of stratified stream deposits, such as Toano Draw, aquifer materials commonly exhibit a fairly large range of hydraulic properties.

The values of transmissivity considered to be representative of the aquifer properties at each test well are as follows:

TW-1	7200 gpd/ft
TW-3	2600 gpd/ft
TW-12	20,400 gpd/ft
TW-14	11,700 gpd/ft
TW-15	50,400 gpd/ft
Well 41-65-35ad	42,570 gpd/ft

These values are the rounded-off averages of the transmissivity values reported in Table 4-2 for each test location.

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It is important to note that the very late-time drawdown data from many of the tests, particularly wells MW-3, MW-12, TW-12, TW-14, and TW-15, show a diminishing rate of drawdown with time. This effect is probably caused by a delay in release of water from storage in the finer-grained portions of the aquifer near these wells. Such an effect increases the apparent transmissivity of the aquifer, possibly only for a short time, to values higher than those reported above. Thus, for the purpose of predicting long-term aquifer response from these tests, it is more conservative to use the estimated average transmissivity values shown above. However, the water-level measurements in observation well MW-17, during the long-term pumping test of well 41-65-35ad (Figure 4-17), also show a similar effect of diminishing drawdown with time. Data from well MW-17 show that the rate of drawdown decreased after pumping for a period of approximately 48 hours. Thereafter, this diminished rate of drawdown continued steadily until the end of the test, approximately 330 hours after pumping began in well 41-65-35ad. This pumping response indicates that the apparent increase in transmissivity that occurred in this well and others after pumping periods of 1 to 2 days is probably not a short-term transient effect but rather is representative of the long-term water transmitting capacity of the aquifer at these locations.

The values of storage coefficient calculated from the drawdown data and the averages of the data at each of the observation wells range from approximately 1.3×10^{-3} to 1.2×10^{-4}. Representative storage coefficients can also be calculated from the drawdown data at pumping wells if the well efficiencies are fairly high. As shown in Table 4-5, estimated values of storage coefficients calculated from the pumping well data are consistent with the values calculated from the observation well data.

The values of storage coefficient (specific yield for unconfined aquifers), which were calculated from the aquifer test data, are lower than typical values for unconfined conditions in unconsolidated sedimentary

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aquifers, such as these in the Toano Draw Subbasin. The calculated storativities from the aquifer tests in Toano Draw are more indicative of semi-confined conditions. However, the specific yield of the aquifer, which would be relevant to long-term pumping, would be much higher than the storativities calculated from the short-term pumping tests. A common range of specific yield for unconfined sand and gravel aquifers is 0.01 to 0.30 (Freeze and Cherry 1979). The effective porosity values measured in the laboratory on samples of the aquifer sediment, which were collected from boring TW-3 while drilling using the cable tool method, range from approximately 30 to 38 percent (Table 4-3). Although there is some uncertainty in how well these samples represent in-situ conditions because of the disturbance in porosity that results from sampling unconsolidated sediments in this manner, these lab values would be consistent with specific yield values in the upper end of the range commonly reported for alluvial sediments, possibly greater than 20 percent. Therefore, considering the variability and depositional environment of the sediments, the specific yield of this aquifer is estimated to range from approximately 10 to 20 percent.

To enable estimation of hydraulic characteristics in areas with relatively limited well data, an empirical relationship between transmissivity and specific capacity was developed. As shown in Table 4-4, values of transmissivity and specific capacity are known for eight wells in this region. These values are plotted on Figure 4-19. Using the least square method of regression analysis, the regression line shown on Figure 4-19 was drawn. The resulting correlation coefficient for the seven data points is high ($R^2 = 0.99$), thus indicating a close linear relationship between specific capacity and transmissivity for the available aquifer tests. From this regression analysis, values of either transmissivity or specific capacity may be estimated if either of the two parameters is known for a well in a similar hydrogeologic setting.

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4.7 GROUNDWATER USE IN THOUSAND SPRINGS BASIN

Groundwater in the Thousand Springs Basin is used for a variety of purposes, including domestic and municipal, live stock and wildlife, and irrigated agriculture. There is currently no identified groundwater use associated with oil or gas production, mining, or manufacturing activities in the Basin.

Various published reports provide information on historical groundwater use in the Thousand Springs Basin. These information sources include Rush's 1968 Water-Resources Appraisal of Thousand Springs Valley, Guyton Associates' 1982 Report on Ground Water Conditions in the Thousand Springs Creek Area, and Gabbay's 1987 Ground Water Supplies for the Indian Springs Project. The Nevada Regulations for Drilling Water Wells (Morros 1985) provided information on regulatory requirements and constraints on domestic wells, useful for estimating potential domestic well water production.

In addition to these published information sources, in 1988 Woodward-Clyde Consultants conducted a well and spring inventory, which is discussed in detail in Section 4.3. Figure 4-1 shows the locations of the 240 wells identified in the inventory and tabulated in Appendix I. Information regarding water well completion details was obtained from driller logs and supplemented during the field well inventory. Eight industrial wells were identified; all are currently unused. The industrial wells were apparently associated with sand and gravel quarries or oil and gas exploration.

Current use of groundwater in the vicinity of the proposed power plant is limited to stock watering.

4.7.1 Domestic, Municipal, and Stock Watering Uses of Groundwater

Morros (1985, p. 12, part 12.01) stated that "a domestic well must be of sufficient depth to provide a capacity of 1800 gpd [2 acre-feet/year], taking into account the normal annual fluctuations and, if the well is in a

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developed area, some annual drop in static water level." Additionally, 'domestic [water] use' is defined to extend to "culinary and household purposes, in a single-family dwelling, the watering of a family garden, lawn, and the watering of domestic animals," under Chapter 534.010 of the Nevada Revised Statues.

Rush (1968, p. 36) noted that groundwater is pumped from wells for domestic use in all four hydrologic segments of the Thousand Springs Creek Valley -- Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, Rocky Butte Area, and Montello-Crittenden Creek Area. He estimated that the net pumpage in each segment for domestic and stock watering uses probably was less than 50 acre-feet/year.

For the purposes of this overall Basin resources evaluation, Mr. Rush's estimate of fewer than 200 acre-feet/year of domestic, municipal, and stock watering uses within the Basin is considered still applicable and conservative. The estimated current population of the Thousand Springs Basin is about 200 persons, of which about 150 people live in the town of Montello and vicinity (Rush 1968). No significant growth in population within the Basin has occurred since the estimates of Mr. Rush were prepared, and little growth is expected during the operating life of the Thousand Springs Power Plant. A conservative estimate of the average domestic use of water in this area is 200 gallons per person per day, calculated on an annual basis, and on that basis the total domestic water use is about 45 acre-feet/year.

The livestock-carrying capacity of range within the Thousand Springs Basin probably does not exceed about 10,000 cattle (about 1,000,000 acres, 1 animal per 100 acres). Assuming an average water consumption of 10 gallons per day per animal, the total annual direct water use to support livestock would be on the order of 110 acre-feet/year. The combined estimated totals for domestic, municipal, and livestock water uses (155 acre-feet/year) are consistent with Mr. Rush's estimate of less than 200

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acre-feet/year for the Basin as a whole. Even if the use were to expand by a factor of five, to 1000 acre-feet/year, over the life of the power plant project, the quantity would be less than the probable error in the estimates for both the quantity of water available within the Basin and the projected power plant uses. Accordingly, it is considered appropriate to not address this category of water use in greater detail in this analysis.

4.7.2 Irrigated Agricultural Use of Groundwater

According to Rush (1968 p. 1), "agriculture, other than grazing, is limited to the mile-wide floodplain of Thousand Springs Creek, where hay and pasture land are irrigated. Sampled well and surface waters were generally chemically suitable for irrigation in the three western (hydrologic) segments [Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, and Rocky Butte Area], but samples collected in Montello Valley were more highly mineralized."

The Elko, Nevada office of the Soil Conservation Services (SCS) provided data in February 1989 on current irrigated acreage, irrigation water uses, and source of irrigation water in the Thousand Springs Basin. Those data are summarized in Table 4-5. The SCS data indicate that irrigated agricultural uses of water in the Basin currently are significantly greater than those reported by either Rush (1968) or Guyton (1982). The SCS data are representative of the same time period as other data collected for this investigation and, therefore, provide consistency in the data base used for these analyses.

Net consumptive use of groundwater by irrigated agriculture in the Basin currently is about 4200 acre-feet/year. In addition, surface water diversions and springs contribute about 11,060 acre-feet/year to irrigated agriculture in the Basin. The SCS estimates that the efficiency of water use by irrigated agriculture is in the range of 30 to 50 percent, and, therefore, about 2.3 times as much water (35,535 acre-feet/year) is applied to the land as is consumptively used by the crops being irrigated. As

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discussed in the water rights section of this report (Section 9.0), it is planned that water rights currently used for irrigated agriculture will be converted to industrial use for the power plant.

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5.0 GEOCHEMICAL CHARACTERIZATION OF AQUIFER MATERIAL AND GROUNDWATER

The geochemical characteristics of the aquifer material and groundwater have been evaluated to determine the chemical suitability of the water for use in the plant. In addition, areal trends in concentrations of hydrochemical constituents have been evaluated as a means of further characterizing the groundwater flow system. Existing data have been reviewed and samples of aquifer material and well and spring water have been collected and analyzed as part of this study. The results of this characterization are described below in this section. The potential effect of water resource development on water quality is discussed in Section 10.6.

5.1 AVAILABLE GEOCHEMISTRY DATA ON AQUIFER MATERIAL

The chemical properties of aquifer material that influence the composition of groundwater are mainly a reflection of the mineralogy and composition of the rocks comprising the aquifer. The stratigraphy of the rocks within the Toano Draw basin has been described in detail in Section 3.4 of this report. Five general stratigraphic units have been designated. In order of decreasing age, these units are: Paleozoic carbonate and noncarbonate rocks, middle to late Tertiary volcaniclastic sediments, Pleistocene and late Tertiary alluvial fan deposits, Pleistocene channelized alluvium, and Holocene channelized alluvium. The alluvial channel deposits comprise the alluvial aquifer, which is the principal groundwater bearing unit in the Toano Draw Subbasin. The general compositions of these units are presented by Rush (1968) and Guyton (1982).

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The carbonate and noncarbonate consolidated rocks typically form the core of the highlands and outcrop in the ranges. The rocks range from Cambrian to Permian in age and are principally carbonate rocks such as the limestone and lesser dolomite of the Pequop Formation (Hope and Coats 1976). Additional lithologies include mudstones, siltstones, Triassic marine volcanic rocks, and granitic intrusive rocks. The Tertiary volcaniclastic sediments are composed of rhyolites, andesites, associated tuffaceous sediments, and some basalt flows. The alluvial fan deposits are generally derived from the volcaniclastic rocks and their weathering products, such as clays and devitrified glass. The Pleistocene and Holocene alluvial deposits in the channels are also generally derived as weathering products of the other deposits. They contain rock fragments and alteration products of most of the available source material.

5.2 SOIL SAMPLING AND ANALYSIS

In order to provide additional information on the composition and mineralogy of the alluvial aquifer material, five samples of these sediments from WCC Well TW No. 3 were collected and submitted for petrographic study.

Two types of analyses were conducted on the sediment samples by Core Laboratories (Irving, Texas). Thin section analyses of whole rock samples were performed as well as X-ray Diffraction (XRD) analyses on the clay-size and sand/silt-size fractions. A complete description of the analytical methods may be found in the laboratory reports (Appendix H).

Thin section analysis was performed to provide information on the relationship between rock textures, detrital grains, cement, and matrix composition. The sample fractions are prepared for thin section analysis by first impregnating the sample with epoxy to augment sample cohesion and to prevent loss of material during grinding. A blue dye is added to the epoxy to highlight the pore spaces. Each sample is mounted on a glass

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slide and then cut and ground to an approximate thickness of 30 micrometers. Prepared thin sections were stained to identify certain minerals (e.g., calcite and potassium feldspar). The thin sections were analyzed using a standard petrographic microscope.

XRD analysis provides information on mineral type and abundance. The clay-size fraction is first analyzed dry and then after treatment with ethylene glycol to differentiate expandable clays. The sand/silt-size fraction is made into a pellet using standard powder techniques. All analyses were run on a Phillips APD3600 X-ray diffractometer. The weight percentages of the rock-forming minerals and the relative abundances of the clay minerals were determined by a peak-area-ratio model. The detectability limit is 1 to 2 weight percent.

The thin-section and X-ray diffraction analyses of the five samples of alluvial aquifer sediment show them to be of similar material. They are poorly consolidated tuffs of volcanic origin with the primary constituents being rock fragments, crystals, and glass shards set in a groundmass of clay and devitrified glass. Rock fragments are mostly volcanics, chert, sandstone, and argillite, with lesser amounts of micrite (calcite-containing) clasts and undifferentiated rock fragments. Crystals include plagioclase, quartz, muscovite, hornblende, and pyroxene. Trace abundances of calcite cement and pyrite were observed in the thin section. Most of the pyrite in these samples has been replaced by iron-oxides (limonite, goethite, and magnetite). X-ray diffraction analyses reveal that variable amounts of calcite (3.4 to 10.9 weight percent) and pyrite (0.4 to 1.7 percent), as well as the zeolite mineral heulandite (0.4 to 2.2 percent) are present. The major minerals are quartz, plagioclase, and clays (principally illite and smectite).

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5.3 AVAILABLE GROUNDWATER QUALITY DATA

Groundwater and spring water chemical analyses have been published in several studies conducted in the Thousand Springs Creek Basin. Rush (1968) conducted a water-resources appraisal of Thousand Springs Valley and analyzed major cations and anions in water samples collected from several spring and domestic wells. In the Toano-Rock Spring area he sampled Well 38-66-24d (Figure 4-1) on 6-22-67. Water from this well had a near neutral pH (7.8), dissolved species were predominantly calcium and bicarbonate, and it had relatively low total dissolved solids (TDS <500 mg/L). The three surface water samples he collected from Thousand Springs Creek and Rock Springs Creek in the area had a similar pH but had a variable TDS and sodium was the dominant cation in some cases. Rush (1968) sampled Crittenden Spring (S11, Figure 5-1) in 1967 and found it had a pH of 8.01, low TDS, and was predominantly calcium-magnesium bicarbonate. Guyton (1982) recompiled the hydrochemical data of Rush (1968) and sampled and analyzed water from 15 wells and one spring in the study area. He found that in general the water is primarily a calcium-bicarbonate type with low TDS and a near neutral pH. Gabbay (1987) published a report on the groundwater supply for the Indian Springs Project. As part of this work he collected and analyzed water samples from Cold Spring (43-68-1066, Figure 4-1), Crittenden Spring (S11, Figure 5-1), Rock Spring (44-67-4dd, off map boundary, Figure 4-1), and the stock tank at the Signboard Well (44-68-23db, off map boundary). These waters had a composition similar to that given in the earlier reports. This suggests that water composition is relatively stable over the 20-year period between measurements.

5.4 WELL AND SPRING SAMPLING PROGRAM

WCC conducted a sampling and analysis program of water from 15 springs and 13 wells in the vicinity of the Toano Draw Subbasin to better characterize the water quality and support the hydrological study of the area. The sampling locations are listed in Table 5-1 and shown on Figure

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5-1. This section summarizes the sampling methodology and analytical procedures. Details of the sampling methods are provided in Appendix G.

5.4.1 Sampling Methodology and Procedures

Prior to well sampling, water levels were measured in newly installed monitoring wells and selected existing wells to determine the gradient of the water table so that estimates of groundwater flow direction and velocity can be made. After the measurement of static water level in a well, the standing water in the well bore was removed so that a sample of groundwater representative of the aquifer could be collected. Well purging was conducted using the existing pumping apparatus in the well, if available, or by using a portable, electric pump. At least three casing volumes of water were purged from each well prior to sampling.

Following purging of a well, the temperature, pH, alkalinity, and specific conductance of the water were measured. These parameters are sensitive to environmental conditions and are not easily preserved so they are normally measured in the field. Water samples were then collected and preserved for laboratory analysis of major cations, anions, and trace/minor inorganic compounds in the water. Water samples collected for major cation and trace/minor inorganic compound analysis were filtered in the field with a 0.45-micrometer pore size filter prior to addition to the sample bottle. In addition to the parameters listed above, the tritium concentration and the content of stable isotopes of hydrogen and oxygen were measured in selected samples. A complete list of compounds analyzed in the water samples is given in Appendix G.

Selected seeps and springs were also sampled and analyzed to provide background water quality data and aid in determining the source of the surface water. Grab samples were taken at the surface water sampling locations. Where possible, the water was collected directly in the container used to make the measurement or hold the sample. If the flow was not sufficient to allow for this, then the sample was collected first into

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a clean container that was rinsed with spring water and then transferred into the appropriate sample bottle. Water samples collected for major cation and trace/minor inorganic compound analysis were filtered in the field with a 0.45-micrometer pore size filter prior to addition to the sample bottle. The field measurement procedures and sample bottle protocols for the surface water samples were similar to those for the groundwater samples.

For all water samples a strict chain-of-custody procedure was used to ensure safe arrival of the samples at the analyzing laboratory. The bottles were packed in ice chests with bubblepack or other protective material to prevent breakage, and ice was added to the cooler as a preservative when necessary. Samples were shipped to the laboratories to arrive within the specified holding times for analysis.

5.4.2 Analytical Methods

A detailed list of analytical procedures used by the laboratories is provided in Appendix G. Most of the major cations and trace/minor inorganics were analyzed by Inductively Coupled Plasma Atomic Emission Spectroscopy. Mercury was analyzed by the cold vapor Atomic Absorption method. The major anions were analyzed by ion chromatography and fluoride was measured by an ion-specific electrode. The stable isotopes of hydrogen and oxygen were analyzed by mass spectrometry and the tritium analyses were done by low-level gas proportional counting.

5.5 GROUNDWATER CHEMISTRY AND QUALITY CHARACTERISTICS

5.5.1 Areal Trends in Water Quality

The majority of the groundwater samples reported in Table 5-1 show that calcium and bicarbonate (reported as alkalinity) are the dominant cation and anion, respectively. In several cases (MW-1, MW-2, MW-4, and Well 40-65-10) sodium is the dominant cation. The cation dominance of sodium relative to calcium may result from increased residence time and reaction

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between the groundwater and the aquifer material. Trends in several hydrochemical constituents reflect the generally northward groundwater flow path that exists within the central portion of the Toano Draw Subbasin. Wells TW-14, TW-15, TW-3, Toano No. 1, 40-65-10, and MW-4 are located in a line that is generally parallel to and along this flow path. The Wells TW-14, TW-15, and TW-3 are located in areas of the subbasin that contain relatively younger water of a calcium bicarbonate type. As contact time increases, i.e., with increasing distance along this flow path, the sodium concentration in the water increases from 15 to >50 mg/L and surpasses calcium. The modified water composition is apparent in the data from downgradient wells MW-4 and 40-65-10. This trend is probably a result of the higher solubility of sodium minerals and the exchange of dissolved calcium for sodium adsorbed on the clay surfaces. The dissolved sulfate also increases with distance along this flow path but does not surpass the bicarbonate concentration.

The areal trends in chloride, TDS, and silica concentrations in groundwater and spring water provide useful information on groundwater recharge characteristics and chemical reactivity of the aquifer materials. As can be seen from Figures 5-3 and 5-4, the TDS and chloride concentrations in Toano Draw and the surrounding highlands show a noticeable distribution of low values in the south-central portion of the Draw and higher levels in the northern portion of the Draw near Thousand Springs Creek. This pattern supports the hypothesis that recharge occurs in the southern and possibly south central portions of Toano Draw and that relatively fresh water moves rapidly with the shallow portions of the alluvial aquifer in the Draw, northward toward Thousand Springs Creek. The low chloride and TDS values compared to some values in the nearby highlands suggest rapid flushing and short residence time for this water. The higher concentrations in the uplands surrounding the subbasin may be a result of longer residence times (contact time between water and rock), slower flow velocities, and less flushing along these flow paths. The sulfur odor detected in the artesian water produced from the lower portion of the MW-1

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boring may be indicative that the deep groundwater has had a long-residence time along a deep regional flow line. Silica concentrations (S_iO_2) in groundwater are illustrated on Figure 5-2. The high silica concentrations of 60 to 70 mg/L for even the young water with a short contact time with the rock is probably a result of the high reactivity of the volcanic glasses in the sediments that allow for rapid dissolution of silica-containing phases.

5.5.2 Water/Rock Interactions Controlling Water Chemistry

The chemical properties of aquifer material that influence the composition of groundwater are mainly a reflection of the mineralogy and composition of the rocks comprising the aquifer. However, in many cases the major minerals present in the rock do not provide the dominant influence because of their relatively low reactivity on the time scale of groundwater residence time. Oftentimes, it is the minor and trace minerals in the rock matrix, or minerals that occur as cementing agents, that control water chemistry. These minerals include calcite, pyrite, clays, and metal hydroxides.

The thin-section and petrographic analyses of the rock samples showed that calcite, pyrite, clays, and iron oxides are components of the aquifer material. Much of the pyrite had been altered to iron oxides, which is expected under the oxidizing conditions that currently exist at least in the shallow aquifer. The hydrogen released by the oxidation of pyrite is neutralized by reaction with calcite, which is present at higher concentrations in the rock than pyrite. Therefore, as pyrite in this rock is oxidized, the pH of the water remains in the neutral range.

It appears, by comparing the spring and well water samples, that most of the major ion chemistry is fixed very early during contact time of precipitation/snowmelt with the shallow alluvium/bedrock. This is quite common. The dissolved calcium and bicarbonate, which are the dominant species in the water, are a product of biological activity, carbon dioxide

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gas exchange with the atmosphere, and calcite equilibrium. The other major cations and anions come from dissolution and leaching of minerals in the aquifer. The metals are trace constituents in the soil.

The stable isotopes of hydrogen (H/D) and oxygen ($^{18}O/^{16}O$) were measured in six spring and eight well water samples because these isotopes have been shown to be useful in "fingerprinting" water types and determining the source of water (meteoric vs. juvenile) in geothermal systems. The results of the stable isotope analyses of all the water samples are given in Table 5-1. They show a relatively small variation in values for the isotopes (delta D = -130 ± 8; delta O-18 = -17 ± 1.6). All the values are close to the meteoric water line. This suggests that all of the groundwater and spring water comes from meteoric sources as rainfall or snowmelt, and that orographic and seasonal effects on stable isotope composition are either minimal or masked by dispersion in the groundwater. The chemistry of the Hot Spring (S7) is discussed separately in the following section.

5.5.3 Geochemical Data Regarding the Origin of Springs

The water chemistry data for the 15 springs sampled show much greater variability than the composition of the groundwater. The total dissolved solids (TDS) of the springs range from 8 to 2140 mg/L, while the TDS range of the groundwater is 187 to 920 mg/L. The pH of the springs also have a relatively wide range of 6.41 to 8.31. The variability in spring composition is expected for springs that discharge from local flow systems, i.e., those that drain small watersheds or shallow, perched zones of groundwater. Local mineral compositions may have a large effect on water composition and evapotranspiration can also have a strong influence on water chemistry along restricted flow paths. In these cases, separate water types can develop, which are then measured as different chemical compositions for the springs. The major cations and anions of the various springs are similar; however, the overall concentrations are different because of variable groundwater residence times and concentrating factors

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(most likely evapotranspiration). Four of the six springs sampled had measurable tritium (Figure 5-5), supporting the hypothesis that the springs discharge a relatively shallow system and are not at the end of a deep groundwater flow system.

The Hot Spring (S7) has a somewhat different chemistry than the other springs. Its TDS is relatively high (515 mg/L), pH is low (6.4), and sodium is the dominant cation. The temperature of water from the Hot Spring (60.9C) is at least 40 degrees higher than that of the other springs and this allows for water/rock interactions to proceed at a faster pace. Also, calcite ($CaCO_3$) becomes less soluble at higher temperatures so calcium may be removed from the water as this mineral precipitates. The presence of tritium in the Hot Spring water and the fact that the delta-D and delta O-18 values of this water are not significantly different from the other spring and well water samples suggests that water in the Hot Spring is relatively young (<50 years old), has a meteoric water source, and has probably not reached isotopic equilibrium with its host rock.

5.5.4 Water Quality Impacts on Plant Operation

Guyton (1982), citing a letter from E.D. Banks, states that water for plant operation having or exceeding any of the following characteristics should be avoided, if at all possible:

1. Silica (SiO_2) - 75 mg/L (35 mg/L as Silicon, Si)
2. Specific Conductance - 2000 micromhos per cm at 25°C
3. Chloride + Sulfate - 500 mg/L

None of the waters sampled during this investigation exceeded the specific conductance limit and only Tripon Pass Spring exceeds the chloride + sulfate limit. The water from Tripon Pass Spring is an unlikely major source of water for the plant because of its low discharge rate of less than 1 gpm. None of the spring water samples exceeded the silica level; however, four of the well samples (TW-3, MW-4, 40-65-10, and 41-65-35ad)

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exceed the silica limit and one well (39-66-24) is at the limit. These wells are all located along the Toano Draw and thus represent the most likely source of water for the first operating plant. Therefore, in general, this groundwater quality appears favorable for plant uses. However, the potential effect of high silica water on plant operation should be further evaluated, and the possible necessity of pre-treatment methods should be considered.

5.6 HYDROCHEMICAL MODEL

5.6.1 Groundwater Recharge

Some aspects of the chemistry of the groundwater can be used to estimate the age of the water and provide qualitative information on recharge to the aquifer. Tritium is a radioactive isotope of hydrogen that has a half-life of 12.26 years. A large amount of tritium was added to the atmosphere during atmospheric testing of nuclear weapons in the 1950s and 1960s. Some of the tritium dissolves in precipitation and its presence in groundwater is a good indicator of whether or not the groundwater has mixed with recent (post 1952) water (Fontes 1980). If tritium is in the water, then some component of the water is a result of recharge within the past few decades. Tritium was analyzed in water from eight wells for this study (Figure 5-5) and detected in four of the wells (TW-3, TW-15, Toano No. 1 [24bd], and Fivemile Draw [33ac]). This suggests that recharge through the unsaturated zone in the vicinity of Toano Draw is occurring and is relatively rapid. The wide distribution of wells with detectable tritium also suggests that recharge may be occurring along the entire Toano Draw and may not be entirely localized in the highlands or southern portion of the Draw.

5.6.2 Hydrochemical Variations along Flow Paths

The areal trends of major cations and anions were described previously in Section 5.5.1. Major changes in cation/anion chemistry were not noted, except for the increasing concentration of sodium relative to calcium along

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potential flow paths. In almost all cases, the analyses of water samples from this study are very similar to results obtained by previous investigators. This suggests that the chemical system is relatively stable both temporally and spatially.

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6.0
SURFACE WATER HYDROLOGY

6.1 INTRODUCTION

This section of the report presents the results of analyses to assess the surface water resources of the Thousand Springs Basin in northeastern Nevada. The analyses were performed as part of the Basin water resources evaluation required for developing general plans to supply water to the proposed Thousand Springs Power Plant. The purpose of the study was to provide information needed for estimating the hydrologic balance. The proposed power plant, at ultimate planned development, will contain eight coal-fueled, 250-megawatt generating units. Each generating unit will require a maximum of 4000 acre-feet/year of makeup water to support its operation.

The renewable water resources of the Thousand Springs Basin are derived from precipitation falling within the watershed boundary of the Basin. Groundwater levels and flows (Section 4.0) were characterized as another part of the overall project water resources evaluation. Results of hydrogeologic characterization indicate that groundwater flow divides exist along the topographically elevated watershed boundaries. Thus, there is no groundwater inflow as underflow into the Basin.

For the purposes of this study, the basin of concern lies upstream from the United States Geologic Survey's (USGS) Montello streamflow gaging station, located about 1 mile upstream from where the Thousand Springs Creek flows into Utah and the Great Salt Lake Basin. Outflow from the Thousand Springs Basin at the Montello station consists of surface water flow in the

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stream channel, which is measured by a recording gage, and underground flow.

A water budget (hydrologic balance) was performed for the Thousand Springs Basin to provide an estimate of groundwater recharge within the basin, and groundwater outflow from the aquifer as underflow, independent of that developed during hydrogeologic characterization groundwater flow modeling activities (Sections 7.0 and 8.0). In order to estimate the basin hydrologic balance, the total basin precipitation was estimated and equated to total evapotranspiration within the Basin plus surface and groundwater outflow. It is noted that within the basin as a whole, there is, and has been historically, relatively little water development and use when considered in relation to the total water resources of the basin.

It is expected that the power plant water requirements will be supplied from wellfields that tap the groundwater resources of the Basin. As a result, the present equilibrium in the groundwater system will be modified. One result of this modification is expected to be that, as the power plant approaches the planned ultimate size, some of the groundwater which presently discharges from the Basin will instead be captured by the project wellfields. An important focus of this study was to estimate the average annual streamflow in the Thousand Springs Creek under present conditions, the extent to which this flow contributes to groundwater recharge, and how recharge rates will change after the power plant begins operation.

In summary, the objectives of the surface water hydrology investigation were:

- To provide estimates of long-term average annual precipitation and the extent to which precipitation recharges the groundwater system`

- To provide information on groundwater-surface water interaction and estimates of the gains to or losses from Thousand Springs Creek due to groundwater flow

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- To characterize the seasonal and long-term variations in precipitation and, if feasible, streamflow

The scope of this investigation included:

- Compilation and analysis of available precipitation records to derive long-term average monthly and annual precipitation and to derive annual precipitation-elevation relationships

- Compilation and analysis of available streamflow records to estimate long-term average annual streamflows

- Compilation of water uses in the Basin - primarily irrigated agriculture

- Estimates of evapotranspiration in the Basin as a range of percentage of average annual precipitation, for use in one method of estimating the Basin water budget

- Estimates of the hydrologic budget for the Basin and selected subbasins

6.2 AVAILABLE HYDROLOGIC DATA AND HYDROLOGIC BACKGROUND

Available hydrologic data for the Thousand Springs Basin include hydrologic data collected for this project and previously published hydrologic data. Estimates of precipitation, streamflow, and reservoir stage data were collected periodicially by Chilton Engineering and Surveying Ltd., Elko, Nevada (Chilton) during 1982 and 1985, and 1986 to 1988. It is noted that the only available streamflow data for Thousand Springs Creek prior to about 1985 were the intermittent (about once a month) measurements made by Chilton. Sources of published data were the National Oceanic and

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Atmospheric Administration (precipitation), the Bureau of Land Management (precipitation-elevation), and the U.S. Geologic Survey (streamflow). Figure 6-1 shows the location of available surface water data stations.

6.2.1 Hydrologic Data Collection

A field program to collect hydrologic data in the site vicinity was performed by Chilton Engineering, which later became Kennedy/Jenks/ Chilton. The hydrologic monitoring stations for precipitation, streamflow, and reservoir stage data are shown on Figure 6-1. Data at each station were obtained by field measurement on an approximately monthly basis. More frequent measurements were sometimes taken following major rainfall events and during periods of high runoff. These data were collected initially to provide approximate measures of streamflow, because there was no existing record of flow, to provide indications of how precipitation varied around the watershed, and later to supplement the published hydrologic data discussed in Section 6.2.

The periods of record for the Chilton hydrologic monitoring data are shown in Table 6-1. As may be seen, data collection at most stations began in February and March 1982 and continued through September 1983. Field data collection was discontinued between October 1983 and January 1986, after which time certain monitoring stations were added and others deleted. Data collection, on a schedule of approximately once a month, at the new set of stations resumed in February 1986 and continued through October 1988.

The Chilton hydrologic data included information from precipitation stations, streamflow stations, and reservoir stations. Precipitation data were cumulative precipitation since the last measured date, for monthly or shorter periods. Streamflow data were instantaneous flow estimates in streams, based on direct current measurement using a current meter, or estimates based on the observers' estimates of flow velocity and channel cross section. Reservoir stage data were measurements of stage relative to

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a bench mark. The precipitation data were based on nonstandard rain gages and were not used in the following analysis.

The Chilton hydrologic data were collected on a periodic rather than a continuous basis. These data were not used for the detailed hydrologic analyses which are discussed later, since flow conditions between times of field measurement were not known. Furthermore, the data were collected during two periods of about 1½ and 2½ years, respectively, with a break between measuring periods of about 4 years. Therefore, they were considered not suitable for use in estimating long-term Basin characteristics. Due to these and other limitations, the Chilton hydrologic data were used only for qualitative interpretation of Basin characteristics.

6.2.2 Published Hydrologic Data

The hydrologic monitoring stations for published precipitation and streamflow data in the site vicinity are shown on Figure 6-1. The reporting agencies, types of data, and periods of record for these stations are shown in Table 6-2. A discussion of these stations and the data provided for subsequent hydrologic analyses are presented below.

As shown in Table 6-2, precipitation is monitored by the National Oceanic and Atmospheric Administration (NOAA) at five locations in the site vicinity. Three of these monitoring stations (Contact, Montello, and Wells) had daily records at least 40 years in length. Data from these stations were used to estimate long-term average monthly and annual precipitation in the site vicinity.

In addition to the NOAA stations, the Bureau of Land Management (BLM) operated a network of 23 rain gages in the Rock Springs Creek watershed from 1963 to 1980. The locations of these gages are indicated on Figure 6-1. The BLM stations were at elevations ranging from 5460 to 7380 feet. While no longer in operation, these BLM stations provided

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monthly totals of precipitation which were used with the NOAA Monitoring Station data to estimate the orographic variations in precipitation in the site vicinity.

As shown in Table 6-2, streamflow is monitored by the U.S. Geological Survey (USGS) at three locations along Thousand Springs Creek. These three gaging stations, which have been identified by the USGS as the Wilkins, Shores, and Montello gaging stations, have drainage areas of approximately 68, 483, and 1453 square miles, respectively. Although having relatively short periods of record (maximum range 1985-1988), the streamflow data from these gaging stations were used for detailed hydrologic analysis since continuous flow measurements are recorded at the stations. Lands of Sierra, Inc. shares in the cost of operating these stations through a cooperative program with the USGS.

In addition to the three continuous gaging stations, the USGS operates eight other stream gaging stations in the site vicinity. Five of these stations are crest-stage gages, and three are stations where spot measurements are made on an as-convenient basis. These stations are not shown on Figure 6-1 nor included in Table 6-2, because instantaneous streamflow data from these stations were not utilized quantitatively in the subsequent hydrologic analysis.

6.2.3 Hydrologic and Meteorologic Setting

Thousand Springs Creek Basin lies within the Great Basin and is drained by Thousand Springs Creek, flowing west to east and discharging to the Great Salt Lake Desert. Four north-trending mountain ridges divide the Basin into seven subareas or subbasins: Herrell Siding Area, Brush Creek Valley, Toano Draw, Rocky Butte Valley, Rock Springs Valley, Crittenden Creek, and Montello Valley. Elevations range from about 4600 feet (1400 meters) on the valley floor, near the Utah state border, to about 8900 feet (2700 meters) in the mountain highlands.

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Winters are long with snow on both valley floors and mountains. Summers are short with warm daytime temperatures and cool nights. Winter precipitation includes snowfall and rainfall, which account for most of the storms. Winter storms are frequently frontal storms. Except for occasional thunderstorms, little precipitation occurs in late summer and early fall. The variability of storm size and temporal distribution is high. The average monthly precipitation is affected by the number, intensity, size, and distribution of storms.

Streams originate at the higher elevations in the watershed and are generally intermittent. The exceptions are several small perennial streams in the headwater areas of the surrounding mountains, and Thousand Springs Creek below Twentyone Mile Dam where streamflow also is generally perennial. Streamflow in Thousand Springs Creek is variable from month to month and from year to year, as well as from location to location. In the reach above Twentyone Mile Reservoir, streamflow decreases in the downstream direction, indicating natural stream losses to groundwater recharge. However, there are some perennial springs, especially downstream from Twentyone Mile Dam, which contribute flow to the Creek.

6.2.4 Precipitation and Streamflow Characteristics

The data described in Section 6.2.2 were used to illustrate the distribution of precipitation and streamflow in the site vicinity. The total monthly precipitations for the Contact, Montello, and Wells precipitation monitoring stations for the period 1985 through 1987 are shown on Figure 6-2. The average monthly streamflows for the Wilkins, Shores, and Montello gaging stations during the same time period are shown on Figure 6-3. Clearly, the average total monthly precipitation values are effected by the number, size, and distribution of storms in the Basin.

As may be seen on Figure 6-2, precipitation is highly variable from month to month. As later discussed in Section 6.3.1, May and June generally are the wettest months, and February and July are the driest

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months, based on long-term precipitation records. Although the available streamflow records were too short to constitute an adequate base for calculating monthly streamflow characteristics on averages, it appears that high streamflow periods occur during late winter or spring as a result of snowmelt on the higher elevation parts of the Basin. As may be seen on Figure 6-3, streamflow is generally highest during the spring and is highly variable from year to year. Streamflow generally decreases in the downstream direction along Thousand Springs Creek. The reduction of streamflow in the downgradient direction is a result of both groundwater recharge from water in the stream channel and surface water withdrawals for irrigation purposes.

Analysis of precipitation and streamflow data in the region are presented in Sections 6.3 and 6.4, respectively.

6.2.5 Basin Surface Water Uses

Surface water in the Thousand Springs Creek Basin is used for a variety of purposes, including recreation, livestock and wildlife, and irrigated agriculture. There is currently no identified surface water use associated with oil or gas production, mining, or manufacturing activities in the Basin. Water use derived directly from springs is considered to be groundwater in this report and is therefore discussed in Section 4.7 (Groundwater Use in Thousand Springs Basin).

Limited published information provides data on historical surface water use in the Thousand Springs Basin. The source of this information is "Water Resources Appraisal of Thousand Springs Valley" (Rush 1968). In addition to this source, the U.S. Soil Conservation Service (1988-1989), Elko, Nevada has provided useful information for estimating current irrigated agricultural use of surface water. The Rush (1968) data are summarized for background information and are not used in subsequent analysis.

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Recreational Use of Surface Water. Twentyone Mile Reservoir is an irrigation reservoir with some flood control and recreational use. Dake Reservoir is a recreational reservoir used primarily for fishing. Crittenden Reservoir is a recreational reservoir with some irrigation use.

Livestock Use of Surface Water. Data on surface water use for livestock and wildlife are currently not available, but such use is thought to be negligible compared to the total water use in the Basin. Generally, livestock obtain their drinking water primarily from wells, and wildlife obtains its water from creeks, springs, reservoirs, and ponds.

Irrigated Agricultural Use of Surface Water. Surface water is currently used for irrigation of native and improved pasture at several locations along the Thousand Springs Valley. Additionally, surface water and springs are used to augment wells for irrigation of alfalfa haylands in the lower portions of Thousand Springs Valley, below Twentyone Mile Reservoir.

According to Rush (1968, p.1), "agriculture, other than grazing, is limited to the mile-wide floodplain of Thousand Springs Creek, where hay and pasture land are irrigated. Sampled well and surface waters were generally chemically suitable for irrigation in the three western [hydrologic] segments [Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, and Rocky Butte Area], but samples collected in Montello Valley were more highly mineralized." Currently, irrigated agriculture remains limited to the floodplain of Thousand Springs Creek and Crittenden Creek.

Rush (1968, p. 32) says that "water is diverted from Thousand Springs and Crittenden Creeks for irrigation on their floodplains. Most of the diverted flow of Thousand Springs Creek west of Eccles Ranch is from snowmelt. East of the ranch, springs and seeps supply most of the diverted flow. Most of the diverted flow of Crittenden Creek is from Crittenden Spring (42/69-8b)."

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Rush (1968, p. 2) estimated that crops in the Thousand Springs Valley consumed 4700 acre-feet/year of surface water on 6400 acres. Rush distributed the 4700 acre-feet/year as 1500 acre-feet/year in the Herrell Siding-Brush Creek Area, 2000 acre-feet/year in the Toano-Rock Spring Area, 200-acre-feet/year in the Rocky Butte Area, and 1000 acre-feet/year in the Montello-Crittenden Area. He reported the growing and presumably irrigation seasons as 70 to 100, 90 to 140, 90 to 140, and 80 to 140 days, respectively.

Rush (1968, p. 32-33) based net consumptive-use rates for meadow, pasture, and alfalfa on Houston (1950), and concluded that the rates average about 1.5 feet per season for two cuttings. He also noted that pumped and/or subirrigation groundwater use supplemented surface water consumed by crops in the Herrell Siding-Brush Creek, Toano-Rock Spring, Rocky Butte, and Montello-Crittenden Creek areas (1968, p. 33). Presumably, subirrigation groundwater is water derived from shallow groundwater by crop roots. He estimated that the 1500 acre-feet/year of surface water used on crops in the Herrell Siding-Brush Creek Area was used, along with 300 acre-feet/year of pumped water and 800 acre-feet/year of subirrigation, on 1700 acres of meadow grass and alfalfa on Winecup Ranch; the 2000 acre-feet/year of surface water used on crops in the Toano-Rock Spring Area was used with 1000 acre-feet of subirrigation on 2000 acres of mostly meadow grass on Winecup and Eccles Ranches; the 200 acre-feet/year of surface water used on crops in the Rocky Butte Area was used with 400 acre-feet/year of subirrigation on 400 acres of alfalfa on Eighteen Mile Ranch; and the 1000 acre-feet/year of surface water used on crops in the Montello-Crittenden Creek Area was used, along with 1000 acre-feet/year of pumped water and 1400 acre-feet/year of subirrigation, on 2300 acres of meadow grass and alfalfa on Crittenden, Twelve Mile, and Gamble Ranches.

In 1988 and 1989, the U.S. Soil Conservation Service (SCS), Elko, Nevada conducted site reconnaissances of irrigated agricultural practices

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in the Thousand Springs Creek Basin. Woodward-Clyde Consultants reviewed the data generated by the SCS and estimates that the current use of surface water for irrigated agriculture is about 11,060 acre-feet/year over 6657 acres. This usage is distributed as 2966 acre-feet/year in the Herrell Siding-Brush Creek Area on 1454 acres of improved pasture, 2799 acre-feet/year in the Toano-Rock Spring Area on 1700 acres of native and improved pastures, 1278 acre-feet/year in the Rocky Butte Area on 1160 acres of native and improved pastures, and 4017 acre-feet/year in the Montello-Crittenden Creek Area on 2343 acres of native and improved pastures and alfalfa haylands.

According to the SCS, the current surface water use estimates are based on net consumptive-use rates which range from 0.95 to 2.21 feet per season. Consumptive use estimates by crop type and number of cuttings are as follows: native pasture, 0.95 feet for one cutting or for one and one-half cuttings using tail water irrigations, 1.43 feet for one and one-half cuttings, 1.91 feet for two cuttings; improved pasture, 1.53 feet for one and one-half cuttings, 2.04 feet for two cuttings; and alfalfa haylands, 2.21 feet for the entire growing season (presumably two cuttings). The term "one and one-half cuttings" means that only one cutting applies to some lands, while two cuttings applies to other lands and represents an average for the area and for the year.

The current estimates of water use for irrigation by subbasin, based on SCS data, are presented in Table 6-3. The table includes net water use and acreage discussed above. In addition, the table includes water-applied volumes based on indicated application efficiencies, and the previous net consumptive use estimates. The table also shows water sources, such as Thousand Springs Creek, Brush Creek, Crittenden Reservoir, and wells and springs. Based on the indicated application efficiencies, the total volume of water applied to all subbasins is about 27,217 acre-feet/year over 6657 acres for all surface water sources (creeks, reservoirs, and springs).

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For comparative purposes, current use of groundwater for irrigated agriculture (alfalfa haylands) is about 4159 acre-feet/year over 1882 acres. The total volume of water applied to all subbasins is about 8318 acre-feet/year over the same acreage, based on the application efficiencies indicated in Table 6-3, for all groundwater sources (wells).

6.3 ANALYSIS OF PRECIPITATION

Analysis of precipitation for the Thousand Springs Basin includes discussion of average precipitation, orographic relationship, and correlation relationships for precipitation.

6.3.1 Average Precipitation

The average precipitation in the site vicinity was calculated on both a monthly and annual basis. This analysis made use of NOAA precipitation data at the Contact, Montello, and Wells precipitation monitoring stations. These stations were selected due to their geographic proximity surrounding the proposed plant site and their periods of record of at least 40 years. Because of these two factors, data from these stations are useful for estimating long-term precipitation in the site vicinity.

The analyses to estimate average precipitation at the three monitoring stations were performed using data from 1949 through 1983. This 35-year period was selected for analysis because it represents the longest concurrent period of record at all three stations. By using this concurrent period of data, the average precipitation quantities reflect the aerial variation which exists between the monitoring stations. Appendix B shows the annual precipitation records (Table B-2) for these stations.

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The results of the analyses of average precipitation at the Contact, Montello, and Wells precipitation monitoring stations are presented in Table 6-4 and on Figure 6-4. May and June are the wettest months, having average precipitations of 1.33 and 1.14 inches, respectively. February and July are the driest months, with average precipitations of only 0.55 and 0.52 inches of precipitation, respectively; overall, February through April and July through October tend to have an average precipitation of less than 0.75 inches/month. The average annual precipitation for all three monitoring stations is 9.41 inches and ranges from 7.69 inches at Montello to 10.37 inches at Wells. These averages are arithmetic averages.

Additionally, the 1949-1983 annual average precipitation for Montello and Wells monitoring stations was compared to the longer term records at these stations. There is no comparable longer term record at the Contact Station. The 1949-1983 Montello station annual average of 7.69 inches compares closely to the 1886-1983 Montello station annual average of 7.57 inches, or about 1.59 percent higher than the longer-term average of 97 years. The 1949-1983 Wells station annual average of 10.37 inches compares closely to the 1890-1983 Wells station annual average of 9.89 inches, or about 4.85 percent higher than the longer term average of 93 years. The 1949-1983 average annual precipitation for Montello and Wells monitoring stations of 9.03 inches compares closely to the longer term average annual precipitation for these stations of 8.73 inches, or about 3.44 percent higher than the average of the longer term average.

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6.3.2 Orographic Relationship

As noted above in discussing the Contact, Montello, and Wells precipitation monitoring stations, different geographic locations may receive widely different quantities of precipitation over the same period of time. These differences may be thought of as having two components (Gilman 1964): one due to differences in geographic location and the other due to differences in elevation. This latter component due to elevation differences results from the orographic effects on precipitation (Gilman 1964, p. 9-24).

The analysis of orographic effects made use of data at the BLM precipitation monitoring stations located in the Rock Spring Creek Watershed. For each of these stations, its mean annual precipitation during the 1963 through 1980 monitoring period was plotted against the station elevation. A regression analysis was then performed to define the best fit straight line through the data points. Two outlier precipitation points were eliminated from the regression analysis because of their apparent inconsistency with respect to the other precipitation points. Further, the orographic analysis is a regional analysis which does not account for windward or leeward variations in elevation.

The result of analyses of orographic effects, including the regression equation, is shown on Figure 6-5. In addition to data from the BLM monitoring stations, this plot includes the mean annual precipitation during the same 1963 through 1980 period for the five NOAA monitoring stations in the site vicinity indicated in Table 6-2. As may be seen, the data from both the BLM and NOAA monitoring stations reflect the same precipitation versus elevation relationship. The resultant regression line (Figure 6-5) is the best fit straight line through both sets of data and is considered applicable throughout Thousand Springs Basin and its vicinity. Also shown on this figure is the equation of the regression line and the correlation coefficient squared (coefficient of determination) of 0.818. This coefficient represents a good fit of the regression line to the observed data. The value of 0.818 means that the regression line accounts for 81.8 percent of the variability of the observed data points.

The relationship presented on Figure 6-5 was used to estimate annual precipitation at various elevations. For the 1963 to 1980 period, this figure shows the actual relationship between elevation and mean annual precipitation. For other annual periods, annual precipitation at any elevation for a given year may be estimated as follows. First, the point representing the location of known elevation and annual precipitation

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during the given year is plotted on coordinates, as shown. Second, a new line which has the same slope as the actual regression line of Figure 6-5 is drawn on the new plot through the plotted point. From this new line, the corresponding annual precipitation at other elevations may be estimated for the same year.

Additionally, Figure 6-5 may be used to estimate precipitation for periods other than 1 year. The procedure of plotting a new point is similar to that described above. First, the point representing the location of known elevation and cumulative precipitation during the given period of n months is plotted. Second, a new line having a slope of (n/12) times the slope of the actual regression line of Figure 6-5 is drawn through the plotted point. Corresponding precipitation for the n-month period at other elevations may be estimated from this new line.

6.3.3 Correlation Relationship

In addition to the above orographic relationship, correlation relationships (Yevdjevich 1964) were developed for total monthly precipitation at the Contact and Wells stations and Montello and Wells precipitation monitoring stations. This correlation was necessary to estimate monthly precipitation totals which were occasionally missing at the Contact and Montello monitoring stations. To develop these relationships, plots of total monthly precipitation at Contact and Montello versus Wells were prepared for each month. For each set of data, a regression analysis was then performed to estimate the best fit straight line through the data points. These relationships permit the estimation of necessary total monthly precipitation at Contact and Montello based upon the total precipitation during the same month at Wells.

The regression plots and equations for all months are given in Appendix B, Figure B-1. The correlation coefficient squared (coefficient of determination) for these correlation relationships vary from 0.238 to 0.730, indicating large variations in goodness-of-fit and less than the

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previously determined value of 0.818 for the orographic relationship (Figure 6-5).

6.4 ANALYSIS OF STREAMFLOW

Analysis of streamflow in the Thousand Springs Creek included use of a geographical model of the drainage basin and development of a streamflow generation model. These two models are discussed in the following subsections.

6.4.1 Drainage Basin Model

A geographical drainage basin model of the Thousand Springs Basin was developed to assist in the analysis of streamflow. This model was developed using WCC's in-house Geographic Information System (GIS). The GIS is a computerized data base management system designed to store, process, and analyze cartographic data. The drainage basin model was developed from the USGS Jackpot and Wells topographic maps, having a scale of 1:100,000 (1 centimeter equals 1 kilometer) and a contour interval of 40 meters.

The drainage basin model for the Thousand Springs Basin is shown on Figure 6-6. This figure shows the Thousand Springs Basin above the USGS Montello streamflow gaging station, which is located just upstream of the Nevada-Utah border. In the figure, the drainage area has been subdivided into spanning vertical intervals of 120 meters each, or three contour intervals, from the USGS topographic maps.

Included on the overall drainage basin map showing elevation zones are two other categories of lines. The irregular lines of Figure 6-6 represent the boundaries of watershed areas above the Wilkins and Shores streamflow gaging stations, a proposed streamflow gaging location below the confluence with Crittenden Creek, and the Toano Draw Subbasin. The straight lines on the figure represent boundaries of Thiessen polygons for the Contact, Montello, and Wells precipitation monitoring stations. The subareas within

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each polygon boundary are the areas within each watershed that are located nearest to the respective monitoring station. The Thiessen polygon method of estimating the average amount of precipitation over a specific area allows for nonuniform distribution of gages by providing an area weighting factor for each gage (Linsley et al. 1982, p. 71). Orographic effects of precipitation within the polygons are accounted for using the orographic relationship discussed in Section 6.3.2.

A tabulation of the drainage areas, derived from the drainage basin model, is presented in Table 6-5. This table shows the drainage areas within each of the Thiessen polygon subareas previously discussed. Also shown is the total drainage area at each location, which is the sum of the respective subareas. For the drainage areas listed on Figure 6-6, breakdowns of drainage areas within each of the elevation zones are listed in Appendix B (Table B-4).

6.4.2 Streamflow Generation Model

Woodward-Clyde Consultants developed a hydrometeorological streamflow generation model to estimate the long-term streamflow characteristics for the subareas contributing flow to Thousand Springs Creek. Development of the model was necessary because, as previously discussed, no long-term streamflow gaging stations exist in the Thousand Springs Basin. This model utilizes data from long-term precipitation monitoring stations to estimate and predict the long-term streamflow characteristics. Streamflow reflects the effects of runoff, groundwater recharge from water in stream channels, contributions from springs, and surface water withdrawals for irrigation.

The streamflow generation model for Thousand Springs Creek was developed based upon the following methodology:

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1. The periods of record at the Wilkins, Shores, and Montello streamflow gaging stations were examined, and the monthly periods with no missing data were identified. The period of no missing data defined the period of analysis at each gaging station. The total volume of streamflow during the period of analysis at each gaging station, V_S, was determined from the streamflow records. For the Montello gaging station, V_S was adjusted to include estimated changes in storage and evaporation from Twentyone Mile and Dake Reservoirs.

   Reservoir stage data were measured by Chilton Engineers, as indicated in Table 6-1. Volume and area versus elevation curves were provided for Twentyone Mile Reservoir by Chilton and were derived from the USGS Tecoma 1:24,000 scale topographic quadrangle for Dake Reservoir. Evaporation data were based on NOAA (1968).

2. During the same periods of analysis, the total amounts of precipitation received at the Contact, Montello, and Wells monitoring stations were estimated using available precipitation records. Any missing monthly precipitation data at Contact and Montello were estimated from the precipitation during the same month at Wells, based on the monthly correlation relationships for precipitation previously developed.

   For example, if there is a missing month during 1985 through 1988 at Contact or Montello, the precipitation during the same month is first obtained for Wells from Table B-5 (Appendix B). Then, the correlation relationship for that month and the station with missing data is selected from Figures B-1a to B-1l (Appendix B). Finally, the precipitation at the desired station during the missing month may be estimated directly from the regression line shown on the selected correlation relationship figure. The correlation relationships presented in Appendix B may be used to estimate monthly precipitation at Contact and Montello for any concurrent month where monthly precipitation is known for Wells.

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3. The total precipitation amounts within the analysis period at Contact, Montello, and Wells monitoring stations, from Step 2, were utilized as primary inputs for calculating precipitation within the respective Thiessen polygon boundaries for the drainage basins upstream of the Wilkins, Shores, and Montello gaging stations. The orographic relationship for precipitation, described in Section 6.3.2, was used to estimate the corresponding precipitation within each elevation zone within each subbasin within the polygons. The total volume of precipitation over each drainage basin, V_p, was computed from the precipitation depths and applicable areas within each elevation zone.

4. The total volume of streamflow at each gaging station, V_s (from Step 1), was divided by the total volume of precipitation over its drainage basin, V_p (from Step 2). The resultant streamflow coefficient, K, is defined as the fractional amount of precipitation that resulted in streamflow at the measuring point during the period of analysis. The values of the streamflow coefficients, K, for the Wilkins, Shores, and Montello gaging stations were determined to be 0.158, 0.0268, and 0.0027, respectively.

5. The streamflow coefficients, K, derived in Step 4, were then adjusted to reflect average climatic conditions, where the rainfall over the basin is equal to the average annual rainfall. This adjustment was necessary because the precipitation amounts during the periods of analyses (from Step 2) were different than the long-term average values. At Wilkins gaging station, an analysis was performed which accounted for the wet and dry rainfall periods. At Shores and Montello stations, a scaling factor was developed by relating the K values to longer-term and more consistent data at Wilkins.

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The Wilkins analysis included a plot of $V_p/\overline{V}_p$ (see Step 7), where $\overline{V}_p$ is the volume of precipitation under the average annual conditions, versus $K/\overline{K}$. The plot included dry year and wet year and the total period of analysis. A curved line was fitted to the plot. $\overline{K}$ was estimated as the K value corresponding to a value of $V_p/\overline{V}_p$ of unity.

At Shores and Montello, a scaling factor was developed. The factor was based on assigning $(K/\overline{K})$ at Wilkins equal to $(K/\overline{K})$ at Shores and equal to $(K/\overline{K})$ at Montello for the same time periods. As all quantities were known at Wilkins and K was known at Shores and Montello, the $\overline{K}$ values at Shores and Montello were calculated from the above equation.

The average streamflow coefficient, $\overline{K}$, represents the coefficient which would have resulted if the long-term monthly average precipitations had occurred during each month in the periods of analyses. The values of the average streamflow coefficients, $\overline{K}$, for the Wilkins, Shores, and Montello gaging stations were estimated to be 0.246, 0.0270, and 0.0042, respectively. At Shores, the period of analysis (March 1985 through October 1986) was significantly shorter than at Wilkins (April 1985 through May 1988) and Montello (same periods as Wilkins, with 3 missing months), as shown in Table B-6 (Appendix B). This difference in periods of analysis explains why the $\overline{K}$ values for Wilkins and Montello are significantly greater than their unadjusted K values from Step 4, while the K value for Shores is similar to the corresponding unadjusted $\overline{K}$ value from Step 4.

The long-term periods (1949-1983) are wetter (more precipitation) on the average than the short-term periods of analysis (1985-1986 for Shores; 1985-1988 for Wilkins and Montello); therefore, a higher percentage of precipitation would be expected to appear as streamflow during the long-term wetter period. Thus, the long-term

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streamflow coefficients would be expected to be higher than the coefficients derived for the simulation period.

6. The average streamflow coefficients, $\overline{K}$, for the Wilkins, Shores, and Montello gaging stations were plotted against their drainage areas so that predictions could be made of $\overline{K}$ as a function of drainage area. A smooth curve was then drawn through the points, as shown on Figure 6-7. From this relationship, the average streamflow coefficient, $\overline{K}$, can be estimated for ungaged locations along Thousand Springs Creek. Based upon the total drainage area that was shown in Table 6-5, the $\overline{K}$ coefficient for Thousand Springs Creek below Crittenden Creek was determined to be 0.0070.

7. The long-term average annual precipitation amounts at the Contact, Montello, and Wells precipitation monitoring stations were applied to the four basins shown in Table 6-5 so that the average precipitation could be estimated for each subbasin. The total volumes of precipitation over each subbasin under average annual conditions, $\overline{V}_p$, were then determined. These analyses were performed as previously discussed in Step 3.

8. The average streamflow coefficient for each drainage basin, $\overline{K}$ (from Steps 5 and 6), was multiplied by the average annual precipitation volume, V_p (from Step 7), to obtain the average annual streamflow volume, V_s. The volumes $\overline{V}_s$, derived from the streamflow generation model, were then converted to discharges to compare average annual streamflows.

As may be seen on Figure 6-7 and in Table 6-6, the average streamflow coefficients were 0.0042 to 0.0270 for drainage areas above Montello and Shores gaging stations, respectively. These coefficients reflect streamflow conditions affected by irrigation withdrawals and groundwater contributions or losses. The average streamflow coefficient for the

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drainage area above Wilkins gaging station was 0.246, reflecting streamflow conditions unaffected by irrigation withdrawals and groundwater contributions or losses. In addition, hydrometeorological conditions, which affect evapotranspiration rates, upstream of the Wilkins gaging are not representative for the Thousand Springs Basin as a whole because of orographic, geologic, and vegetative differences.

The results of the streamflow generation model for the Thousand Springs Creek are shown in Table 6-6. As may be seen, the computed average annual streamflows were 17.23 cfs and 5.50 cfs at the Wilkins and Montello gaging stations, respectively. When distributed over the respective drainage areas, average annual streamflows equate to 3.45 inches and 0.051 inches of areawide runoff at the same two locations.

This analysis did not evaluate instantaneous runoff but rather evaluated long-term runoff appearing as streamflow at selected locations. Runoff is surface water flow resulting from precipitation; streamflow includes runoff, contributions to or from groundwater, and withdrawals for irrigation. To evaluate runoff, data on short-duration storms and flows are required. The available rainfall and streamflow data were examined and were found inadequate to evaluate runoff and the percentage of rainfall that infiltrates soils to recharge groundwater. Recharge information, however, may be inferred from the hydrologic water budget (Section 6.6).

Because only 3 years of streamflow data were available and the flows were highly variable, these data were unsuitable to characterize monthly streamflow on a long-term basis. However, on a short-term basis, the available monthly measurements were analyzed to provide meaningful qualitative information. For instance, Figure 6-3, which shows average monthly streamflows at Wilkins, Shores, and Montello gaging stations from 1985 to 1987, indicates that flows progressively decrease in the downstream direction. Thousand Springs Creek flows from Wilkins to Shores to Montello Stations. The decrease in downgradient streamflow is a result of ground-

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water recharge from water in the stream channel, surface water withdrawals for irrigation purposes, and evapotranspiration losses along the channel.

Estimates were also made of average annual streamflow for the subbasins of the Thousand Springs Basin identified by Rush (1968). These subbasins are Herrell Siding-Brush Creek, Toano-Rock Spring, Rocky Butte, and Montello-Crittenden Creek. For the purpose of this analysis, the Toano-Rock Spring Subbasin was subdivided into two separate subbasins: Toano Draw and Rock Spring Subbasins. To be consistent with the numerical groundwater model discussed in Section 8.0, Thousand Springs Creek was selected as the boundary between the Toano Draw and Rock Spring Subbasins. Average annual streamflows for each of the subbasins were estimated using the streamflow generation model and methodology outlined previously.

The results of the streamflow generation model for the subbasins identified by Rush (1968) are shown in Table 6-7. As shown, the computed average annual streamflow from the Herrell Siding-Brush Creek Subbasin is 16.85 cfs, or 1.44 inches over the Subbasin. As also shown, the average annual streamflows from the Toano Draw, Rock Spring, Rocky Butte, and Montello-Crittenden Creek Subbasins range from -1.31 to -5.02 cfs, or -0.06 to -0.21 inches, over the respective subbasins. The negative streamflows for these subbasins indicate a net reduction in streamflow due either to infiltration to groundwater, withdrawals for irrigation, or ET losses along the Creek. Additionally, the drainage basin at Montello gage includes all the subareas identified above and has an average annual streamflow of 5.80 cfs or 0.051 inches, which incorporates the effects of current irrigation usage.

The computed average annual streamflows cannot be compared directly with Rush's 1968 estimates for runoff because streamflow estimates account for springflows, groundwater recharge, and consumptive use of surface water for irrigation. Runoff is estimated as that part of precipitation that

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becomes surface flow, i.e., does not infiltrate to groundwater or evapotranspirate to the atmosphere.

6.5 EVAPOTRANSPIRATION

An investigation was conducted to estimate the amount of natural evapotranspiration (ET) which takes place within the Thousand Springs Basin. This activity required the estimation of actual (rather than potential) ET rates for natural vegetative species within the region. Due to the considerable depth to groundwater throughout much of the basin, most of the natural ET is expected to derive from direct evaporation of precipitation and removal of near surface soil moisture by nonphreatophyte vegetation. Along portions of Thousand Springs Creek, where the water table is near the ground surface, additional ET of groundwater by phreatophytes would be expected to take place.

Natural ET is affected by many factors and, hence, is difficult to estimate with precision. ET rates vary with the type and density of vegetative cover, extent of cloud cover, wind velocity and direction, air temperature, humidity, and topographic patterns. Also, for any basin, it will vary from year to year, depending on the total precipitation during the year and the pattern of the precipitation throughout the year. A number of empirical formulae exist that permit estimation of approximate average ET values, based on parameters such as those above that can be readily measured (Veihmeyer 1964). These methods are very approximate and may only be used to estimate potential ET. Potential ET is defined as the ET that would occur if there was an adequate moisture supply present in the soil at all times, rather than the actual ET which would be much smaller in the arid environment of this Basin. In addition, most of these estimating techniques, including the well known Blaney-Criddle Method, were developed to estimate ET for crops rather than for natural vegetation, as is needed here (Blaney 1959; Criddle 1958).

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Due to the inherent limitations in the available analytic techniques, a literature review was conducted to determine whether ET had been estimated or measured for natural vegetation typical of the Thousand Springs Basin. The principal, nonbeneficial phreatophytes throughout the basin have been identified as rabbitbrush, greasewood, and saltgrass (Rush 1968). That reference provides reconnaissance-level estimates of ET from groundwater by these species; i.e., it does not include precipitation and soil moisture. Limited measurements of consumptive use of water by greasewood and saltgrass, made during 1926 and 1927, are available for the Escalante Valley in Utah (Young and Blaney 1942). Additional measurements of consumptive use of water by rabbitbrush, greasewood, and other native species, made during 1963 through 1967, are available for the Humboldt River Valley in Nevada (Robinson 1970). These latter two references provide a total ET for the vegetative species desired, but only in areas of shallow depth to groundwater. Hence, these data would not be applicable to regions with considerable depth to groundwater, as exists throughout most of the Thousand Springs Basin. Furthermore, these data would not be directly applicable to other locations having differences in climate, geology, topography, or density of vegetative cover. No other references which provide estimates or measurements of ET for these species were found during the literature search.

Due to the lack of applicable data, and the limitations of analytic techniques as previously discussed, an alternative method to estimate ET was needed. The approach taken was to estimate average annual ET for the watershed as a whole, expressed as a percentage of the average annual precipitation over the basin.

Estimates of ET are available for the Humboldt River Basin, which is located adjacent to the southwestern portion of the Thousand Springs Basin (Eakin and Lamke 1966). Within this basin, they estimated that approximately 90 percent of the total precipitation is lost to ET "about where it falls," or local ET; e.g., ET prior to that which occurs along stream

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channels. Eakin and Lamke (1966) state that "of the approximately 10 percent of the total precipitation that becomes runoff or groundwater, nearly all of it is ultimately lost by ET within the basin." This estimate is a result of the Humboldt River Basin being a basin of interior drainage, which is not true for the Thousand Springs Basin within Nevada. Therefore, there is a net outflow from the Basin in Nevada to Utah, and the outflow occurs as both surface water and groundwater. For this analysis, no information or data are available which would support an estimate of ET more precise than 90 percent of total precipitation in the Basin as a whole.

The streamflow coefficients previously developed could be used to provide independent estimate of evapotranspiration for drainage areas where streamflow is not influenced by irrigation withdrawals or groundwater contributions or losses; in this instance, evapotranspiration may be computed from precipitation less streamflow (Linsley et al. 1982). These conditions may exist in the drainage area above the Wilkins streamflow gaging station.

The estimated average streamflow coefficient for Thousand Springs Creek at the Wilkins streamflow gaging station is 0.246, as shown in Table 6-6. This streamflow coefficient indicates that average annual evapotranspiration from the drainage area above the gage could not exceed 1-0.246, or 75.4 percent of average annual precipitation. Hence, the previously assumed estimate for average annual evapotranspiration of 90 percent of average annual precipitation would not apply to the 68 square-mile drainage area above the Wilkins station. However, the 90 percent estimate is assumed to be applicable for total ET over the entire 1453 square-mile drainage basin above the Montello streamflow gaging station.

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6.6 HYDROLOGIC BUDGET ESTIMATE

A hydrologic budget estimate was prepared for the Thousand Springs Basin for two reasons: to provide an estimate of groundwater recharge within the Basin, independent of the Maxey-Eakin method presented in Section 8.0; and to provide an estimate of groundwater outflow as underflow leaving the Basin, independent of the groundwater flow model also presented in Section 8.0.

The hydrologic budget analysis quantifies hydrologic inflows and outflows of two components within the Basin: watershed land surface and groundwaters. Under steady-state conditions (no change in groundwater storage), inflow would equal outflow for both components of the water budget. These budgets and associated assumptions are discussed below.

The hydrologic budget for the watershed land surface component may be expressed as follows by equating inflows to outflows:

$$\text{Sum of Inflows} = \text{Sum of Outflows} \qquad (6\text{-}1)$$

$$P + GA = ET + NI + S + IR + GR \qquad (6\text{-}2)$$

where:

P = Average annual precipitation over watershed
GA = Average annual groundwater applied to the watershed from groundwater by wells for irrigation
ET = Average annual natural evapotranspiration from watershed
NI = Average annual irrigation consumptive water use from both surface and groundwater sources
S = Average annual streamflow from watershed
IR = Average annual irrigation return flow from surface and groundwater sources to the aquifer

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GR = Average annual net groundwater recharge from watershed to the aquifer

In the above hydrologic budget (Equation 6-2), average annual precipitation (P) and streamflow (S) are known from the results of the streamflow generation model, as previously discussed (Section 6.4.2). Groundwater applied (GA) is estimated from water applied for irrigation from wells (Section 6.2.5) (data from SCS). Natural evaporotranspiration (ET) is estimated to be 90 percent of average annual precipitation (P), as discussed in Section 6.5. Net irrigation (NI) is estimated from net water use for irrigation from both surface and groundwater sources (Section 6.4.2). Irrigation return flow (IR) is estimated from the difference between water applied for irrigation and net irrigation water use, from both surface and groundwater sources (Section 6.4.2). Net groundwater recharge (GR) is the difference between natural groundwater recharge from the watershed to the aquifer and spring flow from the aquifer to the watershed.

Groundwater recharge (GR) is the unknown term in Equation 6-2, and may be solved by rearranging terms of the equation as follows:

$$GR = P + GA - ET - NI - S - IR \qquad (6\text{-}3)$$

Similarly, the hydrologic budget for the aquifer component may be expressed as follows:

$$\text{Sum of Inflows} = \text{Sum of Outflows} \qquad (6\text{-}1)$$

$$GR + IR = GA + GO \qquad (6\text{-}4)$$

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where:

GO = Average annual groundwater outflow from the aquifer as underflow leaving Thousand Springs Basin

All other terms in Equation 6-4 are as previously defined and estimated as discussed above. Groundwater outflow is the unknown term in Equation 6-4 and may be solved by rearranging terms of the equation as follows:

$$GO = GR + IR - GA \qquad (6\text{-}5)$$

The following assumptions apply to Equations 6-1 through 6-5 above:

- Steady-state conditions prevail; i.e., there is no change in water storage, either in soil moisture or reservoirs (watershed component) or in groundwater storage (aquifer component).
- There is no inflow to the aquifer as underflow, i.e., inflow equals zero.
- All irrigation return flow (IR) recharges the aquifer; i.e., there is no return flow to surface water.
- There is no natural use of groundwater by crops; i.e., sub-irrigation equals zero.
- Surface water irrigation applied is internal to the watershed land surface, and is fully accounted for by net irrigation (NI) and irrigation return (IR) from surface water sources.
- Net groundwater recharge (GR) is natural groundwater recharge from the watershed land surface less natural spring discharge from the aquifer.

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The results of both components of the hydrologic budget analysis for the entire Thousand Springs Basin at the Montello gaging station are summarized on Figure 6-8. The figure presents the hydrologic budget estimates for the evapotranspiration rate considered applicable for the Basin as a whole, i.e., 90 percent of total Basin precipitation. As shown on Figure 6-8, net groundwater recharge (GR) is estimated to be 63,335 acre-feet/year. Outflow (GO) is estimated to be 75,333 acre-feet/year.

The hydrologic budget estimate presented in Table 6-8 is based on existing conditions at Thousand Springs Creek at Montello gaging station. This table includes estimates of net groundwater recharge (GR) and groundwater outflow (GO) derived by other procedures, for comparison with the value computed by the hydrologic budget analysis. The comparative estimate of groundwater recharge (GR) derived by the Maxey-Eakin method (Section 8.0) of 61,236 acre-feet/year is comparable to the 63,335 acre-feet/year computed above. Also, the estimate of groundwater outflow (GO) based on a Darcian flow analysis (Section 7.0 and Appendix J) of 56,740 acre-feet/year is comparable to the 75,333 acre-feet/year computed above.

Because the Thousand Springs Power Plant will be located within the Toano Draw watershed, and initial generating units are planned to be supplied with water from the aquifers underlying the area, a water budget analysis for this watershed was performed. An approximate water budget was developed because streamflows have not been measured in the Draw, although it is known that surface water discharges from the area are rare and generally small in flow rate and of short duration when they do occur. The streamflow generation model developed for Thousand Springs Creek required continuous streamflow measurements, which are not available for Toano Draw. Continuous streamflow measurements in the Basin were only available for three locations. Efforts to apply the streamflow generation model applying the streamflow coefficient for Thousand Springs Creek as a whole over the Toano Draw Subbasin are believed to overestimate streamflow from

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Toano Draw, based upon numerous streamflow observations made by Chilton and others and, therefore, are not presented. Hence, an approximate technique was required to compute the water budget for Toano Draw.

The approximate water budget method for Toano Draw required two steps. First, the water budget for existing conditions at Montello gaging station was modified to eliminate the effects of irrigation; i.e., net irrigation (NI), irrigation return (IR), and groundwater applied (GA) were set equal to zero and adjusted values for streamflow (S) and net groundwater recharge (GR) were computed to reflect the absence of irrigation. Second, the parameter value estimate in the water budget for modified conditions at Montello were multiplied by a scaling factor to approximate the water budget for Toano Draw. The scaling factor was the ratio of the drainage areas of Toano Draw to Thousand Springs Creek at Montello (251.61/1452.73 = 0.173).

The results of the approximate hydrologic budget analyses for modified conditions at the Montello gaging station and Toano Draw are included in Table 6-8. This table shows independently derived estimates of net groundwater recharge (GR) and groundwater outflow (GO) for comparison with the range of values derived by the approximate hydrologic budget for Toano Draw. The Toano Draw estimate of groundwater recharge (GR) derived by the Maxey-Eakin method (Section 8.0) is 11,558 acre-feet/year whereas it is 13,768 acre-feet/year computed by the water budget analysis. Similarly, the estimate of groundwater outflow (GO) calculated by a Darcian Analysis (Section 7.0) is 6100 acre-feet/year and 13,768 acre-feet/year, computed by the water budget analysis. Referring to Equation 6-5 and Figure 6-8, it may be seen that groundwater outflow (GO) is equal to net groundwater recharge (GR) when groundwater applied (GA) and irrigation return (IR) equal zero, as is the case for Toano Draw.

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7.0
WATER RESOURCES DEVELOPMENT FOR PLANT OPERATION

7.1 AVAILABLE WATER RESOURCES

In evaluating the available water resources of the Thousand Springs Basin, it is necessary to consider the amount of perennial (average annual) recharge to the groundwater system at present, the amount of groundwater in storage, and the changes in the rates of recharge and discharge that will occur as a result of developing and utilizing the groundwater resource to supply the power plant project. Early investigators in water resource planning applied the concept of "safe yield" to evaluate the amount of water available from a groundwater basin. As defined by Todd (1959), the safe yield of a groundwater basin is the amount of water that may be withdrawn annually without producing an undesired result, such as intrusion of water of undesirable quality, contravention of existing water rights, or unacceptably severe environmental impacts associated with streamflow depletion. In the classical sense, the concept of safe yield would limit the amount of water withdrawn to the perennial recharge rate of the Basin. It is the general policy of the State Engineer of Nevada to limit groundwater withdrawals to the perennial recharge rate of the basin being utilized.

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It is generally recognized by groundwater professionals that significant economic benefits may be derived, and in some cases insignificant adverse consequences may result from developing a groundwater basin to levels of pumping that exceed the natural rate of perennial recharge in order to take advantage of the potentially large amount of groundwater that may be in storage (Maxey 1968; Freeze and Cherry 1979) and

lower groundwater levels in the basin by pumping, thus increasing the rate of natural groundwater recharge and decreasing the amount of groundwater lost through evapotranspiration and nonbeneficial types of discharge (Maxey 1968; Bredehoeft and Young 1970).

In the concept of "optimum yield" of a groundwater basin, groundwater has value only by virtue of its use, and the optimal yield of a basin is defined by the water development plan that makes use of the available water most effectively (Domenico 1972; Freeze and Cherry 1979). The total renewable surface and groundwater resources of the Thousand Springs Basin are significantly greater than the maximum water requirements of the proposed power plant. Yield optimization for the Basin as a whole, therefore, is not an inherent project requirement. However, considering only the Toano Draw Subbasin, which cannot provide enough water for the entire power plant, project economics are more favorable if the Subbasin yield is optimized and transfer of water from other subbasins is deferred until the Toano Draw resources are developed to their optimum level.

The purpose of this section is to address the potentially available groundwater resources, for pumping at the rates and from the locations which most effectively and efficiently utilize the resources without inducing unacceptable environmental effects. In the subsections that follow, the perennial recharge rates and the amount of groundwater in storage will be estimated. Following this, potential wellfields will be identified in favorable areas, and a wellfield development program outlined in accordance with the presently planned development schedule for the overall project. The general effects of pumping to supply the project will be outlined, based on the groundwater modeling results described in Section 8.0 and further discussed in Section 10.0. The groundwater development plan, which is proposed in Section 12.0, is believed to be consistent with the policy of the State Engineer of Nevada.

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7.1.1 Estimates of Perennial Recharge

There are several lines of reasoning that have been used to estimate the perennial (average annual) groundwater recharge rates. First, an empirical relationship between precipitation and recharge rates, developed by Maxey and Eakin (1949), has been applied. This method has been established as a means of deriving approximate estimates of subbasin groundwater recharge to the arid basins in Nevada (Watson et al. 1976). The details of this analysis are provided in Section 8.2.4.1. Applying this method to the Toano Draw Subbasin, using available precipitation data and orographic relationships, the average annual subbasin groundwater recharge rate has been estimated to be approximately 11,500 acre-feet/year (Section 6.6).

A second hydrological line of reasoning has been used to estimate the recharge rate in this Subbasin. From the results of a hydrologic budget analysis of the Toano Draw Subbasin (Section 6.6), the perennial groundwater recharge within this subbasin watershed is estimated to be about 13,800 acre-feet/year.

The Chilton observations and measurements of streamflow, as discussed in Section 6.0, found that there rarely was flow in the lower reaches of the Toano Draw Channel, near its discharge to the Thousand Springs Creek Channel. When flow did occur, it was generally small in volume and of short duration. Similarly, for all other tributaries discharging into Thousand Springs Creek, downstream from the Highway 93 crossing, surface water discharges were generally small and of short duration. Chilton's observations did not cover the upper reaches of the Toano Draw Subbasin or any other subbasin except in the headwaters area of Thousand Springs Creek, as observed at the Highway 93 crossing, and as presently being measured at the USGS Wilkins streamflow gaging station, located about 3 miles upstream from the Highway 93 crossing.

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Considering the Thousand Springs Basin as a whole and the Toano Draw Subbasin, it seems reasonable to assume that in the headwaters area of the Basin and the Subbasin, on the higher and steeper slopes of the mountains around and within the Basin, precipitation and surface runoff characteristics are similar to those for the Snake Mountains which form the headwaters area of Thousand Springs Creek. For the latter area, large amounts of surface runoff have been observed and measured where Highway 93 crosses the Creek and at the Wilkins streamflow gaging station. Flows in the Thousand Springs Creek Channel decrease progressively in the downstream direction from the Highway 93 crossing. A similar phenomenon is believed to occur in the Toano Draw Subbasin and other subbasins of the Thousand Springs Basin, i.e., the surface runoff from the mountains infiltrates to groundwater as it flows across the long and broad alluvial infill material of the Toano Draw Valley and other areas with similar alluvial deposits.

It is noted that at the Wilkins streamflow gaging station, the total average annual flow in the Creek is estimated to be about 12,500 acre-feet/year, or about 25 percent of the precipitation falling on the watershed area above the gage. It is further noted that this estimate is based on using 18 years of precipitation data collected in the Rock Springs Creek Subbasin, to derive orographic effects on precipitation in northeastern Nevada (as discussed in Section 6.0), and applying this relationship to the headwaters area of Thousand Springs Creek. This analysis used the available short-term (3 years) streamflow data records from the Wilkins streamflow gaging station and the available long-term (35 years) precipitation records for deriving the above precipitation/streamflow relationship.

Further extrapolation of the Wilkins streamflow and subbasin precipitation estimates to indicate a probable qualitative relationship between watershed elevation and runoff may be done by examining Table 7-1, which presents watershed areas within zones spanning 120 meters elevation (approximately 400 feet) and cumulative areas, starting from the highest

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zone within the watershed, for the Thousand Springs Basin as a whole, the Toano Draw Subbasin, and the Wilkins Subbasin. Table 7-1 also includes the estimated total average annual precipitation within each of the elevation zones and the cumulative precipitation starting from the highest zone within each watershed considered in the table.

Based on the relatively large amount of runoff known to occur from the Wilkins Subbasin and the relatively large percentage of the Subbasin area that exists at relatively high elevations (e.g., 32 percent above 2000 meters or 69 percent above 1880 meters elevation), it was judged reasonable that in this Subbasin a substantial portion of the precipitation falling on the higher elevation land appears as runoff. It also seems reasonable to assume that lands at the same higher elevations in other parts of the Thousand Springs Basin would have similar precipitation runoff relationships.

For the Toano Draw Subbasin, it is noted that for all contour intervals below 2360 meters elevation the area within each interval is greater than the corresponding area in the Wilkins Subbasin. Therefore, it seems likely that there is as much or more high elevation runoff from the Toano Draw Subbasin as from the Wilkins Subbasin. But there is practically no surface water discharge from the Toano Draw Subbasin to the Thousand Springs Creek. To account for the high elevation runoff from the Toano Draw Subbasin requires that it be stored, lost by evapotranspiration, or infiltrate to groundwater. There is no significant surface water storage within the Subbasin. The runoff is believed to be a result primarily of snowmelt, when evapotranspiration losses would be relatively low. Also, evapotranspiration rates for the higher elevation zones of the Wilkins and Toano Draw Subbasins should be similar. Therefore, it seems reasonable to expect that most of the runoff from the higher elevations of the Subbasin infiltrates to groundwater within the Subbasin.

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For the Thousand Springs Basin as a whole, for all elevation zones considered in this discussion, there is a greater area of land in each zone (see Table 7.1) than in the Wilkins Subbasin. Therefore, it seems reasonable to expect that for the Basin, there is correspondingly greater runoff from higher elevation lands in the Basin than there is from the Wilkins Subbasin. Based on the available streamflow and irrigation records, there is only a relatively small amount of runoff contribution (about 3000 acre-feet/year on an annual basis) to Thousand Springs Creek below the Wilkins stream gage. Therefore, much of the runoff from the higher elevations of the basin infiltrates directly to groundwater.

For both the Toano Draw Subbasin and the Thousand Springs Basin, the groundwater recharge estimates derived by the Maxey-Eakin procedure seem consistent with and probably conservative (i.e., low) based on the above line of reasoning.

A high rate of deep infiltration for the Toano Draw Subbasin is consistent with the trends noted in the hydrochemical data (Section 5.0). The patterns of concentrations of chloride, total dissolved solids, and tritium indicate that recharge is occurring at a relatively rapid rate along the stream channels, particularly in those channels in the southern-central portion of the Subbasin (Section 5.6). Several wells in Toano Draw that are located near the recent alluvial channels were found to contain measurable tritium content. This indicates that groundwater below the water table in these areas has received recharge from precipitation occurring within about the past 35 years.

By making several reasonable hydrogeological assumptions to simplify calculations, it is possible to use a third line of hydrogeological reasoning to estimate the rates at which recharge water has migrated from the ground surface through the vadose zone to the water table in these areas. (Calculations and Assumptions are provided in Appendix J). Using the available tritium data as an approximate indication of flow rates

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through the vadose zone, the estimated rates of recharge range from approximately 7600 to 12,700 acre-feet/year. The range of values is consistent with the range of recharge rates derived using the hydrologic budget analysis approach and also the recharge rate based on the Maxey-Eakin method.

A fourth method of estimating the perennial recharge rate in the Toano Draw Subbasin is based on available hydrogeological data. By assuming that the perennial recharge of the Subbasin is at least equal to the present steady-state groundwater discharge through the northern end of the Subbasin, it is possible to estimate a "probable minimum" value for long-term perennial recharge rate to the Subbasin. This estimation method may result in a lower than actual recharge rate value because the underlying assumption neglects the possibility of groundwater discharge from the Subbasin through pathways other than shallow groundwater flow through the northern end of Toano Draw.

The rate of groundwater discharge northward through a representative hydrogeologic cross section has been estimated in the northern end of the Subbasin (Cross Section B-B', shown on Figure 3-4), using the following equation (equation 7-1 below). This equation is based on Darcy's Law and assumes steady-state conditions and flow is through a homogeneous, isotropic medium.

$$Q = KiA \qquad (7\text{-}1)$$

where Q = the groundwater discharge rate
i = the hydraulic gradient
K = the hydraulic conductivity
A = the cross-sectional area through which flow occurs.

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In order to estimate Q, values have been assigned to the parameters in this equation, as follows (details of this calculation are presented in Appendix J). The hydraulic gradient, i, was estimated to be 0.003 across the area of the cross section, based on the water table contour map (Figure 4-5). The cross-sectional area for flow, A, was estimated to be about 13,400,000 square feet, using the results of the TDEM survey in the area and geological logs of borings along geological Cross Section B-B' (Figure 3-4). The average hydraulic conductivity value, K, was estimated to be approximately 18 feet/day, based on the results of aquifer tests that were conducted in the Toano Draw area. Inserting these estimated parameter values into the above equation results in an estimate of the groundwater discharge, Q, from the Subbasin northward, to the Thousand Springs Creek drainage system, equal to approximately 6100 acre-feet/year. This value is less than the value estimated for average annual recharge rate based on the hydrologic budget analysis, those values estimated from the tritium data, and those values estimated using the Maxey-Eakin method.

The apparent discrepancy between the recharge rate estimated based on groundwater discharge from the northern end of the Subbasin and the higher recharge rate estimated may be a result of an oversimplified assumption; namely, the assumption that perennial recharge is equal to the discharge from the northern end of the Subbasin. In the hydrogeologic setting of Toano Draw there probably is significant discharge from the Subbasin downward along deep flow lines through the Paleozoic carbonate aquifer to the regional flow system. Such deep discharge through basement Paleozoic rocks would be consistent with the discussions of regional flow through the Paleozoic carbonate aquifer by Rush (1968) and Maxey (1968). It is also conceivable that there may be groundwater flow leaving Toano Draw to the east beneath Twentyone Mile Draw. If the regional flow system in the Paleozoic carbonate aquifer is receiving recharge from the valley fill sediments in the Toano Draw Subbasin, or if there is discharge of groundwater from the Subbasin along another flow path, then the actual perennial recharge rate would be higher than the rate of discharge through Cross Section B-B' in the northern end of the Toano Draw Subbasin.

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To summarize, the various estimates of recharge to the Toano Draw Subbasin aquifer fall within the range of about 6000 to 13,800 acre-feet/year. Discharge from the aquifer is estimated to be about 6000 acre-feet/year through the alluvium at the northerly end of Toano Draw plus some unquantified amount entering the Paleozoic carbonate aquifer that appears to underlie the Subbasin at great depth. Deep groundwater flow through this aquifer may discharge to the east--probably contributing groundwater to the alluvial aquifer in the Montello area. It is concluded that the renewable groundwater resource within Toano Draw Subbasin is at least about 6000 acre-feet/year. In addition to this amount, there is also a significant amount (estimated to greater than about 2000 acre-feet/year) of perennial recharge to the Subbasin along Thousand Springs Creek that may be derived from the areas north of Toano Draw and from the higher elevations of the Thousand Springs Creek watershed to the west of the Subbasin.

An additional water resource present in the Toano Draw Subbasin is a large quantity of groundwater now stored in the aquifer. The estimated total volume of unconsolidated sediment present as valley infill along the broad valley of Toano Draw is 44,000,000 acre-feet. The volume of water stored within this aquifer is probably on the order of 10,000,000 acre-feet (porosity about 25 percent). However, it seems likely that only water present within 100 feet of the water table surface might be available for power plant uses, and that the aquifer within this zone would yield only 10 percent of its gross volume to wells. Based on those assumptions, it is estimated that at least 500,000 acre-feet of water may be present as a potentially available, nonrenewable resource in the Toano Draw Subbasin.

The Maxey-Eakin method has also been applied to estimate the average annual recharge rate for the Thousand Springs Basin as a whole. Using this method, with available precipitation data and the orographic relationship described in Section 6.3, it was estimated that approximately 61,000 acre-feet/year of water is recharged to the groundwater system in the Basin as a

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whole. This estimate is consistent with the estimate of recharge rate derived by the hydrologic budget analyses for the Basin, i.e., about 63,000 acre-feet/year (Section 6.6).

For comparison to these estimates of recharge, an estimate was made of the perennial groundwater discharge rate through the eastern end of the Thousand Springs Valley in the Montello area. For this purpose, a north-south cross section near the Utah State line was developed, based on the results of the line of TDEM soundings run in the area (described in Section 3.3.4). Using the same method to estimate the discharge rate (Q) as described above for the Toano Draw Subbasin, Q has been estimated to be approximately 56,700 acre-feet/year. (Details of this calculation are provided in Appendix J.)

The values of the parameters that were inserted into Equation 7-1 for this estimate were based on available data from wells in the area and were as follows:

$K = 3240$ ft/day

$i = 0.00055$

$A = 3{,}800{,}000$ ft^2

The hydraulic conductivity, K, used for this estimate was based on an average of available data from pumping test conducted in the Montello area. The hydraulic gradient, i, was based on available groundwater level measurements (WCC 1988) near the cross section. The area of the cross section was based on available drillers logs of wells in the area and the TDEM soundings. However, it is noted that the water-bearing sediments may extend to considerably greater depths than those assumed for the estimate of the cross-sectional area, A, provided above, based on the results of the TDEM survey.

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Even though there are significant hydrogeological factors of uncertainty in this groundwater discharge estimate, the estimate indicates that at present there are tens of thousands of acre-feet/year of groundwater discharge from Nevada to Utah in the Montello area. Groundwater flow eastward through the Montello area represents the discharge of the regional groundwater flow system of the entire Thousand Springs Basin. The perennial recharge rate must be higher than the subsurface groundwater discharge rate in order to account for consumptive uses within the Basin (mainly evapotranspiration losses from irrigated agriculture). Thus, there is reasonably close agreement between the estimate of discharge from the Thousand Springs Basin (56,700 acre-feet/year plus 15,200 acre-feet/year net consumptive use by irrigated agriculture) and the amount of perennial recharge predicted by applying the Maxey-Eakin method (61,000 acre-feet/year), and the value estimated from the regional hydrologic budget analysis of the Basin (Table 6-8). It is noted that the estimated annual average surface water flow in Thousand Springs Creek, and discharging across the Utah border, is about 4000 acre-feet/year. This flow is in addition to the groundwater discharge discussed above. The conclusion drawn from these several methods of estimating groundwater recharge and flow is that there is at present significantly more groundwater circulating through the regional flow system of the Basin, and discharging as groundwater from the Basin, than the amount proposed for use by the full-scale power plant development (32,000 acre-feet/year). Additional evaluation of the potential yield of the groundwater system in the Toano Draw Subbasin and vicinity has been conducted using groundwater flow modeling as described below in Section 8.0.

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7.2 OPTIONS FOR WATER RESOURCES DEVELOPMENT

Several resource development options are available for supplying groundwater to the power plant. Potentially favorable wellfield locations for supplying the power plant are outlined on Figure 7-1. The three water

supply options that have been evaluated are summarized in Table 7-2 and described as follows:

Option 1: Withdrawal of 20,000 acre-feet of water/year from wellfields in the Toano Draw Subbasin. The remaining water demand of 12,000 acre-feet/year would be met from wellfields located along Thousand Springs Creek, between Twentyone Mile Reservoir and Montello.

Option 2: Withdrawal of 12,000 acre-feet/year of water from Toano Draw Subbasin. The remaining water demand of 20,000 acre-feet/year would be supplied from wellfields in the Montello area.

Option 3: Withdrawal of 16,000 acre-feet/year of water from the Toano Draw Subbasin. The remaining water demand of 16,000 acre-feet/year would be supplied from wellfields in the Montello area.

The potential of the groundwater system to supply the anticipated needs of the power plant is discussed below. In order to further evaluate the potential groundwater resources of the Basin and the effects of pumping in the potentially favorable wellfield locations, groundwater flow modeling has been performed using numerical and analytical methods (Section 8.0). A schematic layout of wells for a hypothetical wellfield is depicted on Figure 7-2.

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7.2.1 Water Supply for Units 1 and 2 - Options 1, 2, and 3

The amount of water needed to supply the needs of the first two power plant units, 8000 acre-feet/year, can be supplied from a wellfield in the Toano Draw Subbasin. For all three development options evaluated it was assumed that Units 1 and 2 would be supplied water from the same wellfield located south of the power plant site. Based on the available hydro-

geologic data and aquifer test results, a favorable location for this wellfield would be in the southern portion of Toano Draw (Figure 7-1). This rate of groundwater withdrawal would probably be less than the perennial recharge rate in the Subbasin (Section 7.1), especially considering the potential for additional recharge along Thousand Springs Creek. However, because the steady-state water table elevation in the area of the proposed wellfield is about 200 feet higher than the water table elevation at the confluence of Toano Draw with Thousand Springs Creek, pumping of the wellfield at 8000 acre-feet/year will have no effect on the rate of aquifer recharge from the Creek for many years. At present, a significant amount of water is diverted from Thousand Springs Creek, upstream of the Twentyone Mile Dam, for irrigation use. It is estimated that present consumptive use in this area for irrigation is approximately 6000 acre-feet/year (Section 6.2.5). It is proposed that irrigation in this area will be progressively reduced and ultimately terminated at such time as it appears that water supplied to the power plant is affecting the amount of water flowing in Thousand Springs Creek downstream from Toano Draw.

7.2.2 Water Supply for Units 3, 4 and 5 - Option 1

For this option the two areas north of the power plant site in Toano Draw that were identified as potentially favorable for wellfields would both be developed for the project. The identified area, located approximately 2 to 6 miles north of the plant site (Figure 7-1), would be developed first. It is expected that a wellfield at this location would serve generating Units 3 and 4. For Unit 5, wellfield development would be in the potentially favorable area farther to the north and generally lying along the south side of Thousand Springs Creek. Initially, pumping of the Toano Draw aquifer at the rates required to supply Units 3, 4, and 5 would be essentially all from aquifer storage. It is important to note that the data presently available are not adequate for accurate determination of the specific yield of the aquifer. However, based on assumptions that are believed to be conservative, the amount of groundwater potentially

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available from storage appears to be very large relative to potential demands of the power plant. Furthermore, it is expected that within a few years the aquifer would be drawn down to the extent that recharge from the flow in Thousand Springs Creek would be significantly increased and flow in the creek downstream from the Shores streamflow gaging station would be correspondingly decreased. Ultimately, it is expected that the only time there would be surface water flow in the Thousand Springs Creek upstream of Rock Springs Creek would be during times of rapid snowmelt and intense summer storms.

7.2.3 Water Supply for Units 6 and 7 - Option 1

For this option, to supply Units 6 and 7, a wellfield would be developed within the valley of Thousand Springs Creek, between Twentyone Mile Dam and the confluence with Crittenden Creek. Irrigation within the part of the valley near the proposed wellfield, which presently accounts for about 1560 acre-feet/year of net consumptive use of water, would be terminated, and the water made available for the power plant. A transmission pipeline would be required between the wellfield and the power plant. The presently planned route for this pipeline is from a booster pumping station to be located near Eighteen Mile Ranch and through Twentyone Mile Draw to a low saddle (about elevation 5900 feet) about 5 miles northeast of the power plant site. The balance of the requirements for the two units would be obtained from base flow in the Creek and aquifer storage beneath the Creek. Although the data presently available are not adequate for determining if this source can sustain the indicated pumping rate, i.e., 8000 acre-feet/year, it seems possible that it will. It is noted that present pumping rates in the valley, for irrigation purposes, do not appear to significantly stress the aquifer. If monitoring of future pumping effects on groundwater levels (Section 11.0) indicated that the pumping rate needed for both these units could not be sustained in this area, it should be a simple matter to extend the wellfield downstream in the direction of Montello to the much greater quantity of water stored in the aquifer in that area. Also, some or all of the water presently used

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for irrigated agriculture in the area, about 7500 acre-feet/year, can be converted to power plant uses. It is expected that if this option is pursued, the ultimate effect would be to significantly reduce flow in the Creek downstream from Twentyone Mile Dam (Section 10.3).

7.2.4 Water Supply For Unit 8 - Option 1

The water supply for Unit 8, with this option, would be provided from a wellfield in the valley north of the town of Montello. The water would be pumped to the power plant through the transmission main required for supplying Units 6 and 7 with this option. In addition, a transmission main extension would have to be installed within the Thousand Springs Valley, between the booster pumping station at Eighteen Mile Ranch and Crittenden Creek, if it had not already been installed as part of a wellfield expansion required for serving Units 6 and/or 7. The available resources for serving Unit 8 from this wellfield include the water presently used in the area for irrigated agriculture (about 7500 acre-feet/year, net), groundwater recharge from precipitation over the Subbasin (about 12,000 acre-feet/year, based on the Maxey-Eakin estimating procedure) and discharge from the regional, deep flow system in the Paleozoic carbonate rocks being recharged from the mountainous areas of the rest of the Thousand Springs Basin (a major part of the estimated approximately 56,000 acre-feet/year presently discharging to Utah through the shallow groundwater system).

7.2.5 Water Supply For Units 3 through 7 - Option 2

The 20,000 acre-feet/year required to supply water for Units 3 through 7, under Option 2, would all be obtained from a wellfield to be developed progressively in the valley of Thousand Springs Creek, along the reach downstream from its confluence with Crittenden Creek and extending south to near the town of Montello. Exercise of this option would require the installation of a transmission pipeline to deliver the water to the power plant site. It is expected that the pipeline would follow the same route as discussed above with respect to supplying water for Units 6, 7, and 8,

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(Option 1), i.e., it would follow the valley of Thousand Springs Creek from Crittenden Creek to Eighteen Mile Ranch and then Twentyone Mile Draw to Toano Draw. The pipeline diameter would be larger than required for Option 1 to accommodate the larger ultimate flow of Option 2. The transmission system probably would include storage tanks that would serve to blend the water from the different supply wells and thereby permit delivering a more nearly consistent quality water to the water treatment facilities at the power plant. Also, the system probably would include one or more booster pumping stations.

The water resources to be utilized for supplying these 5 units would include the following:

- Transfer of about 9000 acre-feet/year of net consumptive use by irrigated agriculture, downstream from Twentyone Mile Dam, to power plant uses.

- Capture by wellfields of the aquifer recharge from precipitation in the Subbasin. Based on the Maxey-Eakin method of estimating this recharge, there may be an average of about 12,000 acre-feet/year available from this source.

- Capture by wellfields of some part of the present groundwater discharge to Utah - about 56,000 acre-feet/year based on an estimate of the flow through a cross section of the Thousand Springs Valley near the state border. The source of a major part of this water is believed to be the Thousand Springs Basin as a whole and deep flow paths from the Basin recharge areas, i.e., the mountains ringing and within the Basin, to the aquifer in the Montello area via the regional flow system through the deep Paleozoic carbonate rocks.

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- The quantity of aquifer storage, within the upper 100 feet of saturated material, and considering only the area likely to be affected by the project wellfields north of the town of Montello, is estimated to be on the order of 200,000 acre-feet.

The expected effects of increased utilization (above current levels) of the available groundwater resources in the lower Thousand Springs Valley are as follows:

- Surface water and groundwater discharge to Utah will be reduced.
- Irrigated forage crops will no longer be raised in the area.
- Water inflow to Dake Reservoir will be reduced.

Further discussion of these potential effects and possible mitigation measures are provided in Section 10.0.

7.2.6 Water Supply For Unit 8 - Option 2

Present expectations are that there is sufficient water available in the Toano Draw Subbasin to supply the needs of Unit 8. The sources of the water include groundwater recharge from precipitation in the Subbasin. The actual perennial recharge rate in this Subbasin is likely to be significantly greater than the probably conservative estimate adopted for this analysis (8000 acre-feet/year). Also, water in storage in the aquifer is estimated to be at least 500,000 acre-feet within the upper 100 feet of saturated aquifer materials. However, before a firm commitment is made to obtain water from Toano Draw for Unit 8, long-term groundwater level monitoring data (Section 11.0) on the effects of supplying Units 1 and 2 from this source should be collected and analyzed. The approximately 10 years available (minimum) between the initial startup of Unit 2 and the time when wellfield development for Unit 8 should be started should be adequate for assessing if the Toano Draw resources are capable of supplying

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more than 2 units. If the long-term perennial yield proves to be not more than 8000 acre-feet/year, or less, then it is expected that Unit 8 will be supplied from the wellfield north of Montello. For now it is assumed that Unit 8 will be supplied water from a wellfield in Toano Draw.

Numerical modeling of the Toano Draw aquifer to assess aquifer drawdown extent and characteristics indicated that drawdown effects adjacent to Thousand Springs Creek would be significantly less, at the end of the power plant's planned operating life, if the Unit 3 wellfield was located south of the plant site in the same general area as the wellfield for Units 1 and 2, than if it were placed north of the plant site. Based on the results of this modeling, it is tentatively proposed that the Unit 3 wellfield be located south of the plant site. Assuming that the modeling results present a generally accurate portrayal of aquifer drawdown at the end of the planned project operating life, then it is expected that the project will have little effect on the amount of surface water flowing in Thousand Springs Creek upstream from its confluence with Crittenden Creek. Anticipating that present irrigation by Lands of Sierra for forage crops will be ceased in areas along the creek, it may be inferred from the model results that there will not be any significant change in the amount of flow in the creek that infiltrates to the Toano Draw aquifer as recharge. However, there would be a reduction in the Toano Draw aquifer groundwater discharge to the underflow beneath Thousand Springs Creek.

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7.2.7 Water Supply For Units 3, 4, 7, and 8 - Option 3

With this option, the wellfield development north of Montello would be essentially the same as for Option 2, except the extent of the development would be for only 4 units instead of 5 units, and the schedule for development would be extended. The size of the required transmission pipeline would be reduced to accommodate the smaller ultimate capacity, and the extent to which the groundwater resources of the Subbasin would be utilized would be less. However, the environmental effects in this Subbasin with this option probably would be about the same as with Option 2. The

environmental effects likely would be greater upstream from the junction of Crittenden and Thousand Springs Creeks because more water would be diverted for power plant uses in the Toano Draw area with Option 3 than with Option 2.

7.2.8 Water Supply For Units 5 and 6 - Option 3

This option requires developing wellfields in the Toano Draw area for supplying a total of 4 units. That is, relative to Options 1 and 2, it is an intermediate level of development. With Option 3, the wellfield development for Units 5 and 6 would be the same as the development for serving Units 3 and 4 in Option 1, except the schedule for the development would be extended by about 4 years, according to the presently planned schedule for the overall power plant project.

Numerical modeling of the Toano Draw alluvial aquifer indicated that the aquifer drawdown adjacent to Thousand Springs Creek would be significantly less if the wellfield for supplying Units 5 and 6 was all within the apparently favorable wellfield area immediately north of the plant site, than if the wellfield for one of the units was located in the area south of but adjacent to Thousand Springs Creek. Based on these modeling results, it is planned that a single wellfield will be developed to supply water for Units 5 and 6.

The sources of water for Units 5 and 6 with Option 3 would be full utilization of the Subbasin recharge from precipitation and an increase in aquifer recharge from flow in Thousand Springs Creek due to lowering of the water table in the vicinity of the Creek adjacent to the Toano Draw Area. Flow in the Creek would be correspondingly reduced in all reaches downstream from Toano Draw (Section 10.3).

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SECTION 8.0
GROUNDWATER FLOW MODELING

The objectives of the groundwater flow modeling conducted for the Thousand Springs Power Plant Project are as follows:

1. To estimate the groundwater system yield and flow characteristics of the basins underlying Toano Draw and along Thousand Springs Creek north of Toano Draw

2. To estimate the overall water balance for the Thousand Springs Basin, i.e., the rates of natural recharge/discharge and inflow/outflow in the Basin

3. To estimate potential groundwater level decline and effects on streamflow and springs as a result of pumping to meet the water requirements of the power plant

4. To provide information for selecting wellfield locations, estimates of well spacing, and potential sustainable long-term pumping rates

In order to meet the above objectives, a numerical (finite-difference) groundwater flow model has been applied to analyze the groundwater flow system in the Toano Draw Subbasin and vicinity. The area selected for groundwater flow modeling includes the Toano Draw Drainage Basin and part of the Rocky Butte Drainage Basin (Figure 8-1). The area, referred to hereinafter as the model area, is bounded on the north by Thousand Springs Creek in the reach between its confluence with Toano Draw and Crittenden

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Creek, and to the south by the drainage divide along the Pequop Mountains. To the west, the drainage divide formed by the Windemere Hills (Black Mountain) serves as the boundary, while the drainage divide along the Gamble Range serves as the eastern boundary. Accordingly, the model area includes all of the land which drains to Thousand Springs Creek from the south within the reach which forms the northern boundary of the model area. The area enclosed within the model boundaries is about 450 square miles.

A steady-state calibration of the model was performed, representing preproject conditions. The calibration runs simulated flow characteristics of the model area, as well as rates of natural recharge, discharge, and inflow/outflow to the area. Using the calibrated model, the above objectives were evaluated as described below.

8.1 CONCEPTUAL MODEL OF REGIONAL FLOW

The hydrogeology of the model area is presented in Section 4.0. The stratigraphic units of importance for characterizing the groundwater flow system are the alluvial aquifer, the alluvial fan-volcaniclastic aquitard, and the Paleozoic carbonate aquifer. This alluvial aquifer is the principal groundwater bearing unit within the model area and it is present within the central portions of the Toano Draw Subbasin and along ephemeral streams. The alluvial volcaniclastic aquitard is generally located along mountain fronts and on the margins of the valleys. In general, this unit is not capable of yielding economically significant quantities of water to wells because of its low permeability. The Paleozoic carbonate aquifer is exposed in the mountain ranges and it is believed that these rocks are continuous between these ranges at great depth below the Subbasin and are overlain by the alluvial valley sediments. Significant secondary porosity features, including vugular and cavernous openings along fractures, have been observed in outcrops of these rocks along the northeastern margin of the Toano Draw Subbasin and in the Gamble Range. From observation of these

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features it may be inferred that this unit may have high capacity for transmitting groundwater regionally, particularly along deep flow lines. At present, neither the subsurface extent of these fractured carbonate rocks or their actual hydraulic properties are known.

Because of the lack of data and uncertainty of the capabilities of these fractures to transmit groundwater, it was decided to model only the water table aquifer. In doing so, any aerial recharge estimated by the model will be conservative because the model will not account for the additional recharge water that may percolate below the bottom of the water table aquifer.

Pumping tests in the Toano Draw Subbasin show that the alluvial aquifer is unconfined in some areas and semiconfined in other areas. The aquifer is generally unconfined in areas abutting the surrounding mountains and semiconfined in areas abutting Thousand Springs Creek. However, geologic investigations to date have not identified any regional confining layer. Thus, on a regional basis, the aquifer is considered unconfined, although during short periods of pumping, the aquifer will respond more like a semiconfined system. Most of the recharge to the aquifer occurs along the mountain fronts and within the upland areas of the valleys. Hydraulic heads vary from about 6500 feet above mean sea level at the Pequop Well to about 5000 feet at the outlet of the modeled area near Crittenden Creek. Groundwater flow from the mountains is generally convergent towards the central part of Toano Draw and then northerly along the valley axis to Thousand Springs Creek. There also appears to be some groundwater flow from the Toano Draw Subbasin into the Twentyone Mile Draw Subbasin based on the available water table data.

Near Eccles Narrows, close to the extreme north of the modeled area, the flow area along Thousand Springs Creek is restricted by carbonate rock outcrops. Because of this constriction, groundwater levels do not decline as rapidly as the declining land surface (see Figure 4-5). This results in

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groundwater levels much nearer to the ground surface in the area upstream from Eccles Narrows. Because of the near-surface water levels in this northern part of the model area, significant groundwater losses occur due to evapotranspiration. Along other parts of the stream channel, where the groundwater levels are below the water level in Thousand Springs Creek, evapotranspiration losses are much less, and the creek serves as a recharge source to the aquifer. Below Eccles Narrows, near the confluence of Crittenden Creek into Thousand Springs Creek, water levels again are near the land surface. This is probably due to a decrease in the cross-sectional area of the alluvial aquifer, and possibly to upward hydraulic gradients. Depending on the relative elevations of the groundwater and the stage of Thousand Springs Creek in this part of the valley, groundwater may either flow to the creek or water may flow from the creek to recharge the aquifer.

Available data were not adequate to estimate, a priori, the stream-aquifer interaction. This interaction was estimated during the groundwater model calibration using the streamflow data as a guide.

8.2. DESCRIPTION OF THE NUMERICAL MODEL

Groundwater flow modeling for the model area (Figure 8-1) was performed with a modular three-dimensional finite-difference model (MODFLOW, version 3.0). The details of the model are presented in McDonald and Harbaugh (1984). The model requires the flow system to be discretized into homogeneous elements using a finite difference mesh. Aquifer parameters are assumed to be constant for each element but these can vary between elements to reflect any known heterogeneities within the domain. The model consists of a number of subroutine programs (packages), each of which consists of one or more program modules.

Two packages of particular interest for application to the Toano Draw Subbasin are the evapotranspiration and river packages. The evapotrans-

piration package estimates the evapotranspiration losses based on a user-specified maximum evapotranspiration rate at the ground surface and the depth below the ground surface where evapotranspiration losses are assumed to be negligible. Evapotranspiration losses at intermediate depths are determined using a linear interpolation. The river package simulates stream-aquifer interactions based on user-specified conductance of the river bottom sediments. Darcy's Law is used to compute the flow between the stream and the aquifer.

Given appropriate aquifer parameters and pumpage rates, as well as initial and boundary conditions, the model simulates hydraulic heads within the flow domain. Model outputs include hydraulic heads, drawdowns and, if desired, fluxes at specific nodes. Further, the model outputs an overall water balance for the Basin. Based on studies reported in the literature (McDonald 1984), the model algorithm has been well tested and found to be accurate.

for what?

8.2.1 Discretization for the Regional Flow Model

For simulating the regional flow, the model area was discretized into a rectangular area having a total of 3186 nodes with 59 rows and 54 columns (Figure 8-2). Nodal length varies from a minimum of 1667 feet to a maximum of 5000 feet. Nodes tend to be closely spaced in the vicinity of the site of the proposed power plant. The areas represented by each node range from about 65 to 572 acres.

8.2.2 Boundary Conditions

Appropriate boundary conditions and aquifer hydraulic parameters are required in order to effectively simulate subsurface flow in a groundwater basin. Available measured water table elevations within the modeled area were not sufficient to effectively assign all boundary conditions or to draw an adequately detailed water table contour map. For virgin groundwater basins with no significant groundwater development, such as this one, a water table contour map will usually help determine the type of

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boundary conditions to impose. Therefore, to supplement the available data, a linear regression of water table elevation against ground surface elevation was performed as shown on Figure 4-4 (Section 4.4). This regression relationship was found to be:

$$Y = 1.03X - 88.6 \qquad (8\text{-}1)$$

where

X = the ground surface elevation [feet above mean sea level from USGS topo map]

Y = the water table elevation [feet above mean sea level]

The above relationship was used to estimate the water table elevations at selected locations where water table data were not available, and the results used to draw the water table contour map shown on Figure 8-3. Note that Equation 8-1 was not used to estimate water levels with the Toano Draw valley floor since there is a relatively high number of water level data from wells in that area. Therefore, the general flow patterns depicted on Figure 8-3 within the valley floor are judged to be representative of the actual conditions. However, in places where Equation 8-1 was used to estimate water levels (in the vicinity of mountain ranges and Twentyone Mile Draw), the flow directions are only roughly approximate and may not be representative of actual field conditions.

Figure 8-3 shows that "no flow" conditions occur along the mountain ridges because water table contours would tend to parallel the ridges. For the areas along the boundary of the model that do not correspond to mountain peaks, groundwater flow divides were assumed to exist between the modeled area and the adjoining basins. These areas include the gap between Pequop Mountains and the Gamble Range and also the gap between the Windemere Hills and Pequop Mountains. Within the range of depths of wells present and checked within the model area (less than 600 feet deep), flow did not appear to enter or leave the model area to or from adjoining

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groundwater basins. Therefore, the only outlet for groundwater from the model area, apart from evapotranspiration losses (in the areas of shallow water tables) and leakage to streams, seems to be through the narrow alluvial channel immediately upstream from the confluence of Crittenden Creek into Thousand Springs Creek. A constant head boundary condition of 4970 feet above mean sea level was assigned to the node in this region. The boundary conditions for the domain are shown on Figure 8-2. Previous studies conducted in the modeled area by Maxey (1968) and Rush (1968) have made the observation that there is a likelihood of groundwater transfer between subbasins within the Thousand Springs Basin. The existence of groundwater transfer between subbasins seems to be likely, but probably is possible only through deep routes of flow.

8.2.3 Available Data on Aquifer Flow Properties

Six aquifer pumping tests were conducted by Woodward-Clyde Consultants (see Section 4.5) within the Toano Draw Subbasin. The tests showed that the aquifer transmissivity varied from 2600 gpd/ft at Well TW-3 to 50,000 gpd/ft at Well TW-15, as discussed in Section 4.5. The storage coefficient varied from 0.00012 at Well TW-1 to 0.0013 at Well TW-3. Two short duration aquifer pumping tests were conducted by Guyton Associates, Inc (1982). Guyton reported that Well 41-65-35bd had an estimated transmissivity of 11,000 gpd/ft and Well 41-65-35ad had an estimated transmissivity of 26,700 gpd/ft. No equivalent storativity values were reported for these tests. In 1989, Well 41-65-35ad was pumped continuously for 13 days at a rate of 900 gpm by Woodward-Clyde Consultants. From this test, the transmissivity was estimated to be 46,500 gpd/ft with a storage coefficient of 0.003. Equivalent hydraulic conductivities at the pumped wells were obtained by dividing the transmissivity values by the well screen length. If drawdown occurred during a test to a depth below the top of the well screen, the thickness of saturated aquifer was assumed to be the depth of water in the well at the end of the pumping. Using this approach, the hydraulic conductivity was estimated to vary from 3 ft/day at Well TW-3 to 56 ft/day at Well TW-15. A more detailed discussion of these tests is presented in Section 4.5.

Rivers may either contribute water to an aquifer or drain water from it depending on the hydraulic gradient between the river and the aquifer. In this analysis, the direction of groundwater movement is handled automatically within the model. At any particular node, a river supplies water to the aquifer if the river stage is higher than the hydraulic head in the aquifer and vice versa. Since the modeled area is bounded on the north by Thousand Springs Creek, the river package of MODFLOW was used to simulate the interaction between the aquifer and the Thousand Springs Creek.

8.2.4 Model Calibration

The parameters used to calibrate the model included the hydraulic conductivity and areal recharge for the modeled area. Initial estimates of the hydraulic conductivity and the areal recharge were made as discussed below.

8.2.4.1 Initial Estimate of Areal Recharge. To estimate the areal groundwater recharge from precipitation, a variation of the method proposed by Maxey and Eakin (1949) (reported in Watson et al. 1976) was used. Using data for groundwater basins in Nevada, Maxey and Eakin found that groundwater recharge is related to the amount of precipitation (Table 8-1). The percentage of precipitation appearing as recharge increases with increased precipitation to a maximum of about 25 percent when annual precipitation reaches about 20 inches or more. For annual precipitation below 8 inches, Maxey and Eakin (1949) concluded that no significant groundwater recharge occurs. Using the data of Table 8-1, the recharge rate derived by the Maxey and Eakin method corresponding to the mean annual precipitation for each of the five precipitation ranges was estimated. A plot of mean annual recharge against mean annual precipitation showed that a power function could be used to describe the Maxey and Eakin relationship, as shown on Figure 8-4. The plot shows that recharge is related to precipitation by the following function:

$$R = 2.8E\text{-}5(P)^4 \qquad (8\text{-}2)$$

where

R = total annual recharge [in]

P = mean annual precipitation [in]

The coefficient of determination for the above regression is 0.998.

To estimate the annual recharge rate using Equation 8-2, it is necessary to estimate the annual precipitation for each nodal point within the modeled area. Analysis of precipitation data indicates the presence of orographic effects (see Section 6.3.2). The relationship between precipitation and elevation was found to be:

$$P = -12.7 + .0043E \qquad (8\text{-}3)$$

where

P = mean annual precipitation [in]

E = ground surface elevation [ft, above msl]

Equation 8-3 is only valid for E greater than 5000 feet.

The entire modeled area was divided into eleven elevation zones, Appendix C. The mapped area within each elevation zone was estimated, with the aid of an electronic digitizer (Talos Digitizing Tablet). Using Equation 8-3 the mean precipitation within each elevation zone was estimated and Equation 8-1 was then used to estimate the recharge within each zone. By this approach, the total recharge to the modeled area was estimated to be about 18,000 acre-feet/year. The recharge calculated by this method for each grid element was assigned as the initial estimate of recharge. For the model application, no recharge was assumed in areas where carbonate rocks outcrop, but instead, it was assumed that the

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equivalent recharge flowed overland to the next active node downgradient and became recharge in that node.

8.2.4.2 Initial Estimates of the Hydraulic Conductivity. The aquifer hydraulic conductivity has been measured at only seven locations within the modeled area as discussed in Section 8.2.2.2. For simulation purposes, it is necessary to estimate the hydraulic conductivity at each element in the finite-difference grid. Electromagnetic surveys conducted in the Toano Draw Subbasin measured the electrical resistivities of major formation materials, to depths of several hundred feet, at numerous locations within the modeled area. A plot of measured hydraulic conductivity against electrical resistivity indicated a strong linear relationship. The following regression relationship (with a coefficient of determination [R^2] equal to 97 percent) was used as a first approximation method to hydraulic conductivity in grid cells where actual aquifer pumping test data for wells were not available:

$$K = -18.1 + 1.39R \qquad (8.4)$$

where

K = hydraulic conductivity [ft/day]
R = electrical resistivity [ohm-m]
$R \geq 15$

8.2.4.3 Data for Stream-Aquifer Interaction. To simulate the stream-aquifer interaction, it is necessary to input to the model the elevation of the bottom of the stream, the water level elevation, the top width of the stream, the thickness of the stream sediments, and the hydraulic conductivity of the stream bottom sediments. Five cross sections of Thousand Springs Creek at different locations (Appendix D) were available (Chilton Engineering 1989). Stream bottom elevations corresponding to these stations were estimated from topographic maps. Linear interpolation was then used to develop the profile for the part of

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Thousand Springs Creek within the modeled area. The log of Well TW-1, the only well near this reach of Thousand Springs Creek for which geologic logs were available, was used to estimate the thickness of the stream bottom sediments. The representative thickness of the bottom sediments was estimated to be about 30 feet. This value was assumed to be the same for all the river nodes. The horizontal hydraulic conductivity of Well TW-1, obtained from the aquifer pumping test at that location, was found to be about 8 feet/day. Johnson and Morris (1962), reported by Freeze and Cherry, 1979, showed that the ratio of the horizontal and vertical hydraulic conductivities of fluvial deposits varied between 2 and 10. From this a vertical hydraulic conductivity of 1 foot/day was estimated to be the hydraulic conductivity of river bottom sediments.

The depth of water in Thousand Springs Creek is controlled in some sections by the level of Twentyone Mile Reservoir. Between February 1982 and October 1988 (period for which data are available), the water level in Twentyone Mile Reservoir varied from 5156 feet above mean sea level in October 1988 to 5193 feet above mean sea level in March 1983 (Table B-1), with a mean of about 5180 feet above mean sea level. For model calibration, the water level in the reservoir was assumed to be 5180 feet above mean sea level. The water level elevation of the river nodes upstream of the reservoir that will be affected by this reservoir elevation were assigned the same elevation as the reservoir. The depth of water in the other sections of Thousand Springs Creek, not affected by the reservoir elevation, varies from zero (during dry periods) to about 5 feet (during very wet periods). Along areas of Thousand Springs Creek that are not directly affected by the reservoir level, the depth of water in the creek was set equal to 1 foot.

8.2.4.4 Initial Estimates of Maximum Evapotranspiration Rate. The uptake of groundwater by phreatophytes depends on the climate, depth to groundwater, and the type of phreatophyte. Within the Toano Draw Subbasin, deep rooted phreatophyte growth is sparse and as such groundwater depletion

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will be limited to only shallow rooted vegetation. The maximum evapotranspiration rate, if the groundwater surface was near the ground surface, was initially assigned an annual value of 12 inches. The evaporation rate decreased linearly to 0 when the water table surface was at a depth of 10 feet below the ground surface. Robinson (1970) performed quantitative studies of water use by woody phreatophytes such as greasewood, rabbitbrush, willow, and wildrose near Winnemucca, Nevada. He concluded that the annual water use rate varied from 1.2 acre-feet per acre (greasewood) to over 3 acre-feet per acre (willow).

8.2.4.5 Results of Model Calibration. Model calibration was achieved through an iterative process. Aquifer hydraulic conductivity, areal recharge and the maximum evapotranspiration rate were changed for each iteration until the modeled hydraulic heads closely simulated the measured hydraulic heads.

Figure 8-5 and Table 8-2 show the measured and simulated heads at each of the existing 31 wells within the model area for which water level data were available. The "serial number" depicted in Figure 8-5 corresponds with the well number on Figure 8-2. Of these 31 data points, the model overestimates the heads of 12 wells with a mean overestimation of 20 feet and underestimates the heads of 19 wells with a mean underestimation of 11 feet. The mean absolute deviation between the computed and measured heads is 15 feet. The minimum absolute deviation of simulated head from measured head is 0.9 feet at Wells 42-66-35b and 39-65-3ad and the maximum is 102 feet at Well 41-67-22bc. The high discrepancy between the measured and simulated hydraulic head for Well 41-67-22bc needs some explanation. This well is located within Twentyone Mile Draw where the geologic map indicates the presence of carbonate outcrops in some sections. The presence of these outcrops were represented in the model as being either impermeable or of very low hydraulic conductivity. It is possible that some of these outcrops are significantly more permeable than their assumed permeabilities. Another reason may be that the well is located in an area

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where the aquifer has steep gradients and where the model grid is not fine enough to simulate the changing hydraulic heads.

The overall flow patterns, indicated by the simulated water table contour map shown on Figure 8-6, agree well with the flow patterns indicated by the measured water table contour map (Figure 8-3). A linear regression between the simulated and the measured hydraulic heads for the 31 wells, shown on Figure 8-7, shows a correlation coefficient (R) close to 1.0. The best fit curve is given by:

$$Y = 153.4 + 0.97X \qquad (8\text{-}5)$$

where

Y = simulated hydraulic head [ft above msl]

X = measured hydraulic head [ft above msl]

Hypothesis tests were performed on both the slope of the regression line (0.97) and the intercept (153.4). At the 95 percent confidence level, the tests showed that the slope is not different from 1.0 and the intercept is not different from zero.

Several reasons may account for the discrepancy between the measured and simulated water level elevation. First, the spatial variability (heterogeneity) of aquifer parameters probably is more complex than can be specified in a model. Second, the degree of discretization determines how well model results will match actual values. In particular, the measured water level elevation at a well represents a point measurement, whereas the simulated water level at a node represents the average head over the nodal area. This is particularly a problem in the vicinity of sinks and sources where hydraulic heads change rapidly with distance. Finally, for calibration purposes, it was assumed that the aquifer is in steady-state, i.e., there are no significant temporal variations in the hydraulic head. This assumption is generally valid for undeveloped aquifers such as the

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Toano Draw Subbasin, where groundwater utilization is essentially zero. However, some of the water levels may have been measured in wells during a period when there was some minor pumping in the area, which may have resulted in some minor discrepancy between the simulated and the measured value.

Figure 8-8 shows the distribution of calibrated hydraulic conductivity assigned to the model. Generally, the hydraulic conductivity is highest along Toano Draw and in the vicinity of Twentyone Mile Draw. It decreases from a maximum of about 72 feet/day in the southern parts of the basin to about 12 feet/day in the northern parts. However, hydraulic conductivities generally exist to the east and west of Toano Draw and Twentyone Mile Draw.

Results of the calibrated model indicate that, under present conditions, the total average annual recharge to the modeled area is about 8400 acre-feet. As noted previously, this rate of recharge may be substantially less than the actual recharge because the flow model does not take into account possible flow through the deep Paleozoic carbonate aquifer. Under steady-state conditions, the model simulates that about 4600 acre-feet is lost to evapotranspiration at locations of high water table (depth to water less than 10 feet) along Thousand Springs Creek, and 1200 acre-feet leaves the basin as groundwater outflow to the Montello Subbasin. The area where the natural water table is within 10 feet of the ground surface is estimated to be about 10,000 acres. This translates to average annual phreatophyte water use of 5 inches across this area of 10,000 acres. This is approximately equivalent to the water use by a greasewood community covering 35 percent of the area or a willow community covering about 14 percent of the area. These rates of usage are based on the rates of evapotranspiration of these plants as estimated for the Humboldt River Basin by Robinson (1970). Considering the sparse distribution of phreatophytes within the modeled area, the simulated phreatophyte water use is judged to be reasonable.

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Based on the assumptions of hydraulic conductivity of the sediments in the stream channel and the depth of water in the creek, the total amount of water infiltrating from Thousand Springs Creek along its entire reach within the model area into the groundwater system, under steady-state conditions, is 1700 acre-feet/year, and the total baseflow along the entire reach of the creek within the model area is estimated to be 4300 acre-feet/year. This translates to an annual net baseflow to the creek of about 2600 acre-feet. Between the western boundary of the modeled area and the Shores gaging station, net annual baseflow to the creek is estimated to be about 1600 acre-feet. This value is consistent with the streamflow generation model and estimates of irrigation usage which indicate that the sum of groundwater discharge and irrigation return flow between Wilkins and Shores is about 7000 acre-feet/year. The difference between these two values may be that the area covered by the groundwater model does not extend to the Wilkins gaging station. This may indicate that some groundwater inflow occurs between the Wilkins gaging station and the western boundary of the groundwater flow model. Between the Shores gaging station and Twentyone Mile Junction, the groundwater flow model indicates that the creek loses about 1200 acre-feet of water to the aquifer. Below Twentyone Mile Junction to the eastern boundary of the model, the creek receives about 2200 acre-feet/year of baseflow. Hence, for the groundwater flow model, the net annual baseflow to the creek between the Shores gaging station and the eastern boundary of the modeled area is about 1000 acre-feet. This compares with 1500 acre-feet obtained from streamflow analysis as the net flow to the basin from groundwater discharge and irrigation return flow. The overall steady-state water balance for the calibrated model is shown in Table 8-3.

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8.3 REGIONAL FLOW MODEL

The calibrated model was used to simulate the effects of groundwater pumping on the water levels in Toano Draw Subbasin, the depletion of flow to Thousand Springs Creek, and change in subbasin evapotranspiration

losses. Since this is a transient simulation, an additional parameter (specific yield) not required for steady-state calibration, is required for this simulation. Because of the long period covered by the simulation and the possibility of large drawdowns, the pump tests reported in Section 4.0 were considered too short in duration to yield representative values of the specific yield. The values obtained from such short-term tests are generally significantly smaller than the long-term specific yield of this type of aquifer material. Based on the composition of the aquifer material, the specific yield is expected to vary from 0.1 to 0.3 (Walton 1970; Freeze and Cherry 1979; Driscoll 1987). A more detailed discussion of this parameter is given in Section 4.5. The simulations reported here are based on assuming a specific yield of 0.1, the same value assigned by Rush (1968) for these aquifer sediments. Sensitivity analyses assuming a specific yield value of 0.2 showed less drawdown than the simulations presented herein.

In order to maximize the use of the water in the Subbasin, it would be necessary to capture the water that is presently lost as evapotranspiration, reduce the baseflow to Thousand Springs Creek, and simultaneously increase the aquifer recharge from Thousand Springs Creek. However, because of environmental considerations, it would be preferable to maintain the phreatophytes and not significantly alter the natural flow in Thousand Springs Creek. Because of these considerations, several scenarios of groundwater development were addressed. For each scenario, a power plant water requirement of 4000 acre-feet/year per unit and new unit startups at 2-year intervals were input to the model, i.e., Unit 1 starts operating at T=0, Unit 2 at T=2 years, Unit 3 at T=4 years, etc. Each unit would operate for a total of 35 years, and it was assumed that the water requirement would remain constant at 4000 acre-feet/year per unit throughout the operation period. The simulated scenarios were as follows:

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Case 1

This is referred to as the Least Cost Alternative. For this case, it was assumed that water for the first five units would be obtained from the Toano Draw Subbasin; Units 6 and 7 would be supplied from wellfields along Thousand Springs Creek between Twentyone Mile Dam and Crittenden Creek; and Unit 8 would be supplied from a wellfield in Montello Valley. This alternative represents the minimum costs for water pipelines and pumping.

Case 2

This is referred to as the Least Environmental Impact Alternative. For this case, Units 1 and 2 would be supplied from a wellfield in Toano Draw, located south of the power plant site; Units 3 through 7 would be supplied from wellfields in Montello Valley; and Unit 8 would be supplied from a wellfield in Toano Draw. To determine the environmental effects of the location of the Unit 8 wellfield, two model runs were made as follows:

Case 2A. Unit 8 would be supplied from a wellfield north of the plant site.

Case 2B. Unit 8 would be supplied from a wellfield south of the plant site.

Case 3

This is referred to as the Intermediate Cost and Environmental Impact Alternative. For this case, it was assumed that Units 1 and 2 would be supplied from the wellfield south of the power plant site; Units 3 and 4 would be supplied from Montello Valley; Units 5 and 6 would be supplied from wellfields in Toano Draw north of the plant site; and Units 7 and 8 would be supplied from Montello Valley. Like Case 2, two model runs were made to assess the differences between supplying Units 5 and 6 either from a single wellfield or two wellfields, located as follows:

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Case 3A. Units 5 and 6 would be supplied water from a single wellfield located just north of the plant site.

Case 3B. Units 5 and 6 would be supplied water from two separate wellfields, one just north of the plant site and the other nearer Thousand Springs Creek.

Figures 8-9, 8-10, and 8-11 show the assumed locations of extraction wells for Cases 1, 2, and 3, respectively.

The projected effects of these water withdrawals on the water balance of the modeled area is shown in Table 8-4. As expected, Case 1 would produce the highest environmental impacts with the annual net flow to the Creek changing from 2523 acre-feet (at time zero) to -2820 acre-feet after 147 years. Hence, the maximum annual water loss from the creek would be 5343 acre-feet. The least environmental impact alternative (Case 2B) produces a net annual water loss of 1544 acre-feet from the creek. The highest average drawdown in the Subbasin would be produced by Case 1 with an average drawdown value of 50 feet. Cases 2A and 3B would each result in an average subbasin drawdown of about 42 feet. The average drawdown for Cases 2B and 5A would be about 38 and 47 feet, respectively. Figure 8-12 shows the rate of water loss from Thousand Springs Creek with time for the different cases. The estimated drawdowns within the modeled area, at the end of the planned life of the power plant, for Cases 1, 2A, 2B, 3A, and 3B are shown on Figures 8-13 through 8-17, respectively. The estimated water table elevation for Case 2B is shown on Figure 8-18.

By running the model with an assumed aquifer specific yield of 0.2, instead of the 0.1 previously discussed, the drawdowns were found to be much smaller, and therefore, potentially adverse environmental impacts would be reduced in each case.

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8.3.1 Description of Montello Valley

The Montello Valley lies to the east of the Toano Draw Subbasin (numerical groundwater model area). Based on results of the numerical model, groundwater subsurface flow within the alluvium of Thousand Springs Creek from the Toano Draw Subbasin to the Montello Subbasin is about 1200 acre-feet/year. However, there may be a large additional component of flow into the Montello Subbasin along deep flow lines, through the Paleozoic carbonate aquifer. Thus it appears that most of the groundwater flow into the Montello Subbasin is through groundwater recharge within the Subbasin, flow within the alluvium of Thousand Springs Creek, or regional discharge from the Paleozoic carbonate aquifer. The channelized alluvium within the Montello Subbasin has a high capacity for transmitting groundwater flow. Pump tests conducted within the Montello Valley Subbasin (reported in Rush 1968 and Guyton 1982) show that the alluvial aquifer in this basin is much more transmissive than the alluvial aquifer in the Toano Draw Subbasin. Transmissivity values from pump tests reported by Guyton (1982) range from 160,000 gpd/ft to 200,000 gpd/ft. Additional data are available, from both drillers logs and short-term pump tests, on the specific capacity of wells in the area. A correlation between specific capacity and transmissivity using available data for the entire Thousand Springs Basin was made (Section 4.6.3). This relationship was used to estimate transmissivity values in areas where actual long-term pumping test results were not available in the Montello Valley Subbasin. By this approach, the average transmissivity of the channelized alluvium was estimated to be about 140,000 gpd/ft in the area that appears potentially favorable for a well-field to supply the project. Although there are no actual field or lab test data available regarding the specific yield of the alluvial aquifer in this area, based on the composition of the alluvial material, the specific yield of the aquifer is actually probably between 0.1 to 0.3. For the analytical model solution presented below, a transmissivity of 140,000 gpd/ft and a specific yield of 0.2 was assumed for the aquifer.

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For ease of solution, analytical solutions usually assume that an aquifer is of infinite extent. However, in hydrogeologic settings, such as the Montello Subbasin, bedrock outcrops which are assumed to be essentially impermeable are present in the vicinity of pumped wells. Hence, a correction needs to be made to analytical models to account for the boundary effects. The method used to simulate these hydrologic boundary effects in the model is explained in Section 8.4.3. The analytical solution selected for this analysis uses the Theis solution technique. The Theis well functions are calculated by polynomial approximations (Appendix C.3).

8.3.2 Application of Analytical Model to Predict Drawdown from Wellfield

The analytical model described above was used to predict the drawdown from a wellfield. From the simulation cases presented in Section 8.3, the maximum annual water requirement from the Montello Valley would be 20,000 acre-feet, to serve five power plant units. The analytical model was used to simulate the effects of withdrawing 20,000 acre-feet of water annually for a period of 35 years. This demand was distributed equally among 12 potential well sites. These potential well sites were spaced so as to reduce interference between wells. In areas where existing wells appear to be favorable well sites, they were incorporated into the model.

In the Montello Subbasin, the alluvial channel to the north is narrow and is bounded by rock outcrops of Paleozoic age. The model used in this analysis has been modified to represent these boundaries by using the image well method that is based on the principal of superposition of well development predicted by the Theis nonequilibrium well formula. Since the actual transmissivities of the rocks are not known, it was conservatively assumed for purposes of the modeling that these rocks form impermeable boundaries. In this approach, when a well is sufficiently near an impermeable boundary, such that the cone of depression of the well extends to the boundary, an image well (with the same pumping rate as the pumped well) is placed an equal distance on the opposite side of the impermeable

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boundary. Where a river that is hydraulically connected to the aquifer exists, the same procedure is applied, but in this case, the image well is a recharge well or, if appropriate, a line of recharge wells. The image well theory was applied for the proposed wells that are located near such hydrologic boundaries. The location of the boundaries applied to the model is shown on Figure 8-19.

The assumptions used in this analysis are that the aquifer is homogeneous and isotropic; the aquifer is infinite in areal extent; groundwater surface slope is zero; and there is no recharge (except that simulated using image recharge wells). Presently there are no data available to determine whether the aquifer is homogeneous and isotropic. However, because of the relatively small range in values of aquifer transmissivity from available test data, the assumption that the aquifer is homogeneous and isotropic is reasonable. As explained above, corrections were made to the model by using the image well theory to correct for boundary effects. For wells near the impermeable boundaries, image discharge wells (with the same pumping rate as the pumped wells) were placed an equal distance on the opposite side of the impermeable boundaries. With pumping, it is expected that water will infiltrate into the groundwater system as leakage from Thousand Springs Creek. At present, about 9000 acre-feet/year of water is used for irrigation within the Montello Valley Subbasin. It is anticipated that with the inception of the power plant project, these agricultural diversions will cease and, therefore, an additional 9000 acre-feet/year of water will be available in the creek. It is assumed that this additional 9000 acre-feet/year of water to the creek will be induced to recharge the aquifer as a result of pumping. Therefore, for modeling purposes, maximum recharge anticipated from the creek as a result of groundwater withdrawals, was limited to 9000 acre-feet/year. This recharge from the creek was represented in the model as a line source consisting of eight injection wells uniformly distributed along Thousand Springs Creek, with each well injecting 1125 acre-feet/year (700 gpm) of water to the aquifer.

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The Maxey and Eakin method presented in Section 8.2.4.1 was used to estimate the precipitation recharge to the aquifer. Using this method, the areal recharge to the Montello Subbasin is estimated to be 12,000 acre-feet/year. This recharge is assumed to enter the Montello Valley along the edges of rock outcrops (the Gamble Range to the west and the Pilot Range to the east). A line source (represented by 20 injection wells, with each injecting water at 600 acre-feet/year) was specified along the edges of the Gamble Range and Pilot Range outcrops. Water level data within the area selected for the analytical model show that the slope of the water table is very gentle, and therefore, the assumption that the water table is essentially horizontal is reasonable.

The resulting drawdowns in the Montello Valley Subbasin for a total annual pumping rate of 20,000 acre-feet for a period of 35 years is shown on Figure 8-19. The drawdowns within the model area vary from about 2 feet to 40 feet.

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9.0
WATER RIGHTS

9.1 INTRODUCTION

Water for operating the Thousand Springs Power Plant will be purchased, on an as-needed basis, from Lands of Sierra, Inc. Lands of Sierra, Inc. owns extensive lands and water rights in the Thousand Springs Basin, and those lands and the water appurtenant thereto are presently used for agricultural purposes. Under the water sales contract between Lands of Sierra, Inc. and Thousand Springs Generating Company, it will be the responsibility of Lands of Sierra Inc. to locate, drill, complete, and develop all wells required to supply water for the power plant project. Water will be sold to the Thousand Springs Generating Company at the wellhead. Accordingly, it will be the responsibility of Lands of Sierra, Inc. to provide the well pump and driver, and a meter on the pump discharge, and to operate and maintain the pump and meter. Thousand Springs Generating Company will construct, operate, and maintain all facilities required for transporting, storing, and treating water for the power plant; and will perform aquifer monitoring, as may be required by the State Engineer and/or the BLM, of the effects of power plant water uses. It will be the responsibility of Lands of Sierra, Inc. to satisfy the requirements of Nevada's water law in connection with the provision of water for the Thousand Springs Power Plant. This may include perfection of existing permits and applications, changes in existing points of diversion, places of use or manner of use, and the acquisition and perfection of new water rights, or any combination thereof.

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Present plans are that Lands of Sierra, Inc. will continue its agricultural uses of water for the foreseeable future, so long as there clearly is enough water available for both power plant and agricultural uses without inducing unacceptable environmental effects. However, under the terms of its contract with Thousand Springs Generating Company, Lands of Sierra, Inc. will give precedence to supplying the water requirements of the power plant and will curtail its uses of water for agricultural purposes if at any time it appears to either the State Engineer or Thousand Springs Generating Company that there is not enough available water for both types of use.

9.2 SUMMARY OF WATER RIGHTS

A summary of Lands of Sierra Inc.'s water rights and permits as of June 6, 1986 is as follows:

I. Surface Water		Acre Feet
Thousand Springs Decree		23,693.85
Certificates		6,689.29
Permits		11,000.00
	TOTAL	41,383.14
II. Groundwater		
Certificates		8,911.55
Permits		26,280.00
	TOTAL	35,191.55

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The conditions of each existing permit must be fully satisfied before it becomes a perfected water right. As of June 6, 1986, the perfected water rights of Lands of Sierra, Inc. were as follows:

	Acre Feet
Adjudicated surface water rights	23,693.85
Certificated surface water rights	6,689.29
SUBTOTAL	30,383.14
Certificated groundwater rights	8,911.55
TOTAL	39,294.69

From the above it appears that Lands of Sierra, Inc. owns perfected water rights exceeding the maximum potential water requirements of the proposed power plant, i.e., 32,000 acre-feet/year.

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10.0
EFFECTS OF WATER RESOURCE DEVELOPMENT

Groundwater withdrawals to serve the Thousand Springs Power Plant Project may create several potentially adverse effects. These effects include groundwater level declines, reduced surface and groundwater discharge from the Basin, reduced streamflow and spring flows, ground surface subsidence, and deterioration in quality of groundwater and surface water. Groundwater level declines may adversely impact the productivity of wells and will increase pumping costs in direct proportion to the increased lift. Water table drawdowns could result in the decline or elimination of phreatophyte vegetation. Increased pumping costs and/or deteriorating water quality may make irrigated agriculture uneconomic. Possible reductions in streamflow, spring flows, and basin discharge and/or changes in water quality may affect aquatic and wildlife habitat. In this section, each of these potential effects of groundwater utilization is described, assuming wellfields will be installed at the potentially favorable locations and pumped at the rates needed to supply the power plant. Potentially favorable areas for wellfields and groundwater development options were described in Section 7.2. Groundwater level drawdowns as a result of pumping associated with the various water development options considered were evaluated using the numerical and analytical modeling methods described in Section 8.0.

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In general, the discussion that follows relates to the expected results of constructing and operating the power plant in accordance with the presently planned development schedule, i.e., eight generating units, constructed with 2-year intervals between initial startup of the individual units, and each unit having an operating life of 35 years and requiring 4000 acre-feet/year of makeup water throughout its operating life.

10.1 GROUNDWATER LEVEL DRAWDOWN

Groundwater pumping results in the lowering of water levels (drawdown) in an aquifer. The amount of drawdown at a point depends on its distance from the pumping well or wells, the pumping rate and duration of pumping, aquifer recharge rate, the aquifer transmissivity and specific yield, and the point's proximity to an aquifer boundary. Drawdowns increase inversely with aquifer transmissivity and/or specific yield. With lower transmissivity, the area of influence of the pumping well is reduced for a given pumping rate, and therefore, higher drawdowns are required to transmit the water from the aquifer to the well. At the start of pumping, the area of influence of the pumping well is small, and the initial drawdown rates are high, but with time, the area of influence expands and this results in a decrease in the drawdown rate. Drawdown is highest at the pumping well and decreases exponentially with distance away from the well.

As discussed in Section 8.3, groundwater drawdown was simulated for three groundwater development options (alternatives). The major differences between the alternatives were the assumption that three, four, or five generating units would be supplied water from wellfields in the Toano Draw area, and the balance of the requirements for eight total units would be from wellfields along the lower reaches of Thousand Springs Creek in Nevada. The aquifer drawdown effects associated with each of these alternatives and the corresponding water balance of the model area are discussed below. The proposed wellfield locations for the various pumping scenarios are shown on Figures 8-9, 8-10, and 8-11.

10.1.1 Drawdown Created by Groundwater Withdrawal for Case 1

For this alternative (5 units supplied water from Toano Draw Subbasin), the highest drawdowns (about 80 feet) would be produced in the vicinity of the two wellfields north of the power plant. The combined pumping rate from these two wellfields would be 12,000 acre-feet/year. In the vicinity

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of the wellfield south of the power plant, the average drawdown would eventually be about 60 feet with a pumping rate of 8000 acre-feet/year. For the wellfield located between Twentyone Mile Dam and Crittenden Creek, the average drawdown in the vicinity would eventually be about 60 feet for a pumping rate of 8000 acre-feet/year. The overall average drawdown for this alternative would eventually be about 50 feet.

10.1.2 Drawdown Created by Groundwater Withdrawal for Case 2

The groundwater withdrawal rate from the Toano Draw Subbasin for this alternative would be 12,000 acre-feet/year (3 units). As discussed in Section 8.3, two simulation runs were made for this alternative. In both cases a wellfield would be located south of the power plant and the pumping rate from the field would be 8000 acre-feet/year. For the Case 2A alternative, the wellfield for the third unit would be located north of the power plant. For Case 2B, the third unit would be supplied from the wellfield south of the power plant. The greatest drawdown for Case 2A would eventually be about 55 feet and it extends from the south, within the southern wellfield, to the wellfield in the north. The average subbasin-wide drawdown would be about 42 feet. For the Case 2B alternative, the highest drawdown would eventually be about 70 feet (but of limited areal extent). This drawdown is produced within the wellfield south of the plant site. In this case, the average subbasin-wide drawdown would be about 38 feet.

10.1.3 Drawdown Created by Groundwater Withdrawal for Case 3

The groundwater withdrawal rate from the Toano Draw Subbasin for this alternative would be 16,000 acre-feet/year (four units). Like Case 2, two simulation runs were made for this alternative. In both cases, a wellfield would be located south of the power plant and the pumping rate from this wellfield is 8000 acre-feet/year. The wellfields to supply two additional units would be located either within one wellfield just north of the plant site, for the Case 3A alternative, or for the Case 3B alternative, two wellfields with one wellfield just north of the plant site and the other

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farther north near Thousand Springs Creek. The highest drawdown for Case 3A would eventually be about 80 feet and would occur within the two wellfields just north of the plant site. The drawdown in the wellfield just south of the plant site would eventually be about 60 feet. The average subbasin-wide drawdown would eventually be 47 feet. For the Case 3B alternative, the highest drawdown would eventually be about 65 feet, but of limited areal extent, and would be produced within the wellfield just north of the plant site; the drawdown within the wellfield nearer Thousand Springs Creek would eventually be about 60 feet and the drawdown within the wellfield south of the plant site would be about 55 feet. The average subbasin-wide drawdown for this alternative would be about 42 feet.

10.2 EFFECTS ON BASIN GROUNDWATER DISCHARGE

Groundwater withdrawals for supplying the power plant as it expands progressively would reduce the amount of groundwater discharging from the Toano Draw Subbasin and from the Thousand Springs Basin as a whole. The present groundwater use in the subbasin is limited to a few acre-feet/year for stock watering purposes. The present groundwater discharge from the Basin includes about 4200 acre-feet/year of water used consumptively for irrigation purposes and about 56,000 acre-feet/year of groundwater underflow into Utah through the Thousand Springs Valley. For the basin as a whole, it is estimated that groundwater discharge to Utah ultimately would change by amounts approximately equal to the extraction rates for each of the water supply options. The proposed action includes terminating irrigation uses of water to offset part of the power plant water uses. There is at present an unknown but probably significant amount of groundwater presently discharged naturally through evapotranspiration by phreatophytes. Although it is not possible to measure the amount of phreatophyte evapotranspiration (ET), it has been estimated that within the model area (upstream from the confluence with Crittenden Creek), based on parameter values assumed for the numerical flow model, ET by phreatophytes and evaporation in areas of shallow water table totals about 4600 acre-feet/year.

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If water development Option 1 (Section 7.0) were to be implemented, the amount of phreatophyte evapotranspiration near Thousand Springs Creek would be reduced in the area upstream of Crittenden Creek by a factor of about 90 percent of present ET. From results of numerical flow modeling (Table 8-4), it was estimated that ET along these reaches of the creek would be reduced by about 4000 acre-feet/year, and groundwater discharge to the creek would be reduced by about 5300 acre-feet/year. (Effects on streamflow are discussed in Section 10.3 below.) There would be minor effects downstream of Crittenden Creek on ET rates. Groundwater underflow discharge to Utah for Case 1 ultimately would be essentially equal to the groundwater extraction rate.

If Option 2 were to be implemented, there would be less of an effect than with Option 1 on groundwater discharge from Toano Subbasin to areas downstream. There would be less of a reduction in ET in areas along the creek. The flow model predicts that there would be about 500 acre-feet/year less ET then at present in the model area after 49 years of pumping (Case 2B). There would be significant but not quantified reductions (greater than Option 1) in ET in the Montello area.

If Option 3 were to be implemented, the effects of pumping on groundwater discharge would be similar to Cases 1 and 2 for the Basin as a whole. The reduction in groundwater discharge to the stream and by ET would be at intermediate levels between Options 1 and 2.

Before pumping (initial condition), the model indicates that within the model area the average net groundwater flow (baseflow less amount of infiltration from the creek to the aquifer) to Thousand Springs Creek is about 2500 acre-feet/year, evapotranspiration loss is about 4600 acre-feet/year, and subsurface outflow is about 1200 acre-feet/year. For the Case 1 pumping simulation, after 47 years of pumping, the net groundwater flow to the creek decreases to about -2820 acre-feet/year, with the

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negative sign indicating net water loss from the creek to the aquifer. Initially, when only Units 1 through 4 are operating, the effect of pumping on the creek is negligible. This is because the wellfields are located relatively far from the creek and, therefore, their cones of depression do not extend to the creek. In addition, the time period where only the first four units are operating (T = 0 to 8 years from startup of Unit 1) is short and therefore, the effects of the pumping have not been fully developed. With the addition of the fifth unit (T = 8 years), which is located nearer the creek, the drawdowns near the creek become pronounced. This results in higher induced infiltration from the creek, and less baseflow to the creek. The addition of Units 6 and 7 (T = 10 and 12 years, respectively), results in further declines in the groundwater flow to the creek (see the steep slope on Figure 8.12). The rate of flow depletion from the creek starts to decrease with time as the basin approaches dynamic equilibrium with the pumping, after about 20 years of pumping. By the end of year 35, when the first generating unit is scheduled to be deactivated, the depletion rate from the creek becomes almost constant, about 2800 acre-feet/year.

As expected, Case 2B appears to have the least impact on the net flow to the creek. The imposition of Case 2B is estimated to reduce the net flow to the creek from an annual value of about 2523 acre-feet in year zero to about 979 acre-feet in year 49 which represents a net loss of about 1544 acre-feet/year. This is because the pumping scenario for this case calls for the least amount to pumping from the Toano Draw Subbasin, together with the fact that the wellfield is the most distant from environmentally sensitive areas. The Case 2A groundwater development alternative may result in a net loss of about 1859 acre-feet/year. With the application of Case 3A groundwater development alternative, the flow to the creek may reduced by about 2231 acre-feet/year while the Case 3B alternative may reduce the flow to the creek by about 2404 acre-feet/year.

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need analyses beyond yet 49.

10.3 EFFECTS ON STREAM AND SPRING FLOWS

10.3.1 Groundwater Development Option 1

Supplying groundwater to the power plant following Option 1 (Section 7.0) would cause significant decreases in the flow of Thousand Springs Creek downstream from the Winecup Ranch and may reduce or eliminate the flow from some springs located along the creek. In the early years of project development (years 1 through 8, Units 1 to 4) the flow rate of the stream could be essentially maintained by implementing water management practices to reduce irrigation diversions as the power plant is being expanded. There is currently consumptive use of groundwater and surface water along Thousand Springs Creek equal to about 15,200 acre-feet/year. Assuming this amount of consumptive use for irrigation would cease, and an equal amount of groundwater would be supplied to the power plant project instead, streamflows could generally be maintained as at present, so there would be only a nominal long-term net decline in streamflow. However, in later years (years 8 to 47), there would be progressive decreases in the flow rate to Thousand Springs Creek and possibly decreased flow in springs located along the creek. The results of numerical flow modeling (Table 8-4) illustrate the approximate magnitude of the decline in net groundwater discharge to the creek according to the assumed development schedule of the project. Although these values do not reflect the positive effect on streamflow that would be created by eliminating irrigation along the creek, it is apparent that there would be a significant net decrease in total annual flows in the creek after about year 8.

The extent and magnitudes of the simulated drawdowns for this option (Figure 8-13) also illustrate the effects on surface water, given that the Thousand Springs Creek, and springs adjacent to it, is hydraulically interconnected in many areas with the alluvial aquifer that will be pumped by project wellfields. Springs that are located along the lowland margins of Toano Draw may be affected by pumping from the alluvial aquifer in the central part of the Valley, e.g., Mud Spring, Pequop Spring, and Lower

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Deadman Spring. Even though the elevations of these springs appear to be above the water table (as depicted on Figure 4-5), they may be connected with the water table. However, other ephemeral streams, and springs located in topographically more elevated areas above the proposed project wellfields, will not be adversely affected. Ephemeral streams in the upland areas surrounding the Toano Subbasin, and in the mountains that form the basin divides, presently lose water along their lower reaches by natural percolation and contribute to groundwater recharge in the Basin. Because these streams are significantly elevated above the present water table, there will be no effect of pumping withdrawals and resultant drawdowns on these ephemeral streams. Similarly, the springs that are topographically elevated above the present water table in these areas will not be affected by pumping because they are hydrogeologically disconnected from the regional water table (i.e., perched above it) or they represent discharge from small-scale groundwater flow systems as described in Section 4.5.

10.3.2 Groundwater Development Option 2

If Option 2 were to be followed for supplying water to the power plant, the effects of groundwater pumping on streamflows and springflows would be minimal in the areas along Thousand Springs Creek upstream of Crittenden Creek. The results of numerical modeling (Section 8.0) have been used to estimate the potential effects of groundwater withdrawals for this case. Based on the records of flow in Thousand Springs Creek, an average of approximately 12,000 acre-feet/year originates upstream from the Wilkins streamflow gaging station. By contrast, only about 3000 acre-feet/year discharges to the Creek from the approximately 95 percent of the Basin watershed draining to the Creek downstream from the Wilkins gage. The results of numerical modeling indicate there would be a small decrease (about 10 feet maximum) in the water table surface near Thousand Springs Creek with Option 2 and slightly less with Option 2B, and therefore there would be a correspondingly small increase in percolation of Creek water to the aquifer and termination of surface water diversions, for irrigation, as

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proposed, would offset the increased percolation and maintain the flow in the Creek. As illustrated on Figures 8-14 and 8-15, the groundwater drawdowns would be confined mainly to the areas in the south-central portion of the Toano Draw Subbasin. Effects of pumping on wells and springs would be localized to the area in the southern and central portions of Toano Draw. Effects on ephemeral streams and springs in the uplands surrounding the Subbasin would be insignificant for the reasons stated above for Option 1. There may be a slight decrease in groundwater discharge to Thousand Springs Creek, which may become noticeable after about 20 years if one of the wellfields were located in the northern end of Toano Draw (Case 2A) (Table 8-4). However, there would still be a substantial net discharge of groundwater to the creek throughout the project life from the area lying north of the creek.

If the wellfield to supply three units (Units 1, 2, and 8) were located in the southern portion of Toano Draw (Figure 7-1), as simulated in numerical modeling case 2B, there would be an even smaller, and probably unnoticeable, impact on streamflows and spring flows in this area. The net reduction in groundwater discharge to the stream in this case (about 1500 acre-feet/year) would be substantially less than the present amount of consumptive use of water for irrigation along Thousand Springs Creek upstream of Twentyone Mile Reservoir (about 6100 acre-feet/year).

For the areas along Thousand Springs Creek, downstream of Crittenden Creek, there would be substantially greater effects than with Option 1 on streamflow unless mitigation measures were implemented to augment streamflow in environmentally sensitive areas. Results of analytical groundwater flow modeling (Section 8) of the hypothetical wellfield that may be located in the Montello area, indicate that water table drawdown in this area would be less than about 40 feet (Figure 8-19). These results indicate that the flow of Gamble Springs may be affected and there may be an effect on the water level in Dake Reservoir. However, water management alternatives that would utilize the water presently diverted for irrigation could be implemented to mitigate these potential effects.

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10.3.3 Groundwater Development Option 3

The effects of pumping on the ephemeral streams and springs in the Toano Draw Subbasin would be similar to those resulting from Option 2. That is, there would be essentially no effect of pumping on the ephemeral streams in this Subbasin. Effects on springs in this area would be localized to those that are near the proposed wellfields that may be interconnected with the water table. Springs in the upland and mountainous areas should not be impacted by pumping from the project wellfields.

Effects on streamflows and spring flows would be greater for Option 3 than for Option 2, but less than for Option 1. Based on the numerical model simulations of Case 3A and 3B, the net groundwater discharge to Thousand Springs Creek, between Wilkins and Crittenden Creek, would decline from about 2500 to 100 acre-feet/year (Table 8-4). However, anticipating that irrigation diversions would be progressively phased out, the net streamflow should not decrease significantly as a result of implementing Option 3. Rather, in the areas upstream of Crittenden Creek, net average annual streamflow may be maintained as a result of cessation of irrigation diversions, similar to Option 2. During the dry season, however, there could be less streamflow downstream from the Twentyone Mile Dam than presently, unless water releases from Twentyone Mile and Crittenden Reservoirs were timed to compensate for the loss in groundwater discharge at these times of the year. Option 3 would also result in a smaller amount of spring discharge along Thousand Springs Creek, mainly in the area north of Toano Draw and extending downstream beyond Twentyone Mile Dam.

For the area along Thousand Springs Creek downstream of Crittenden Creek there will be similar, but reduced, effects on streamflow relative to those with Option 2. Anticipating that present irrigation uses will cease, and water from Crittenden and Twentyone Mile Reservoirs will be released as needed to augment streamflows, there should only be minimal effects of the pumping on streamflow as a result of implementing Option 3. However, the

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possible effects on flows of Gamble Spring and the Dake Reservoir would be similar to, but probably less than, the effects of implementing Option 2.

10.4 EFFECTS ON IRRIGATED AGRICULTURE AND PHREATOPHYTES

The effects of groundwater withdrawals on phreatophytes would be relatively high if the groundwater resource development proceeded according to Option 1, whereas there would be minimal impacts to phreatophytes if Option 2 were selected, and an intermediate level of impacts if Option 3 were selected. The results of numerical flow modeling (Figure 8-13) of Case 1 show that there could eventually be drawdown of the water table to a sufficiently large degree to adversely impact phreatophyte growth in the areas along Thousand Springs Creek north of Toano Draw and downstream of Twentyone Mile Reservoir. These effects would probably be manifested after development of the wellfield to supply Unit 5 (beginning of year 8) and become progressively larger as the development and pumping proceeded. On the other hand, for Options 2 and 3 the model-simulated drawdowns (Figures 8-14, 8-15, 8-16, and 8-17) appear to be so minor that there would be essentially no impact to phreatophytes in those areas. However, in the Montello area there would be significant groundwater level drawdowns associated with supplying water according to Options 2 and 3. These drawdowns would adversely affect phreatophytes unless appropriate mitigation measures were implemented. Such mitigation measures may include regulated releases of waters from Twentyone Mile and Crittenden Creek reservoirs at selected times, to limit and control the effects.

Another mitigation measure, as proposed above, would be to cease irrigation diversions as at present to offset water uses by the power plant. This practice would adversely impact the current level of agricultural development, which consists mainly of hay production for ranching purposes, but would not preclude continued hay production using dry farming practices at a significantly reduced level of production, or maintaining ranching operations as at present by importing hay to the Basin to offset lost production in the Basin.

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10.5 EFFECTS ON EXISTING WELLS

Withdrawing groundwater to supply the power plant will in general have relatively minor effects on existing water supply wells. These effects include increased pumping costs because of increased lifts resulting from the water table drawdowns near the proposed wellfields. In a few instances, stock watering wells completed at shallow depths below the present water table may eventually go dry because of long-term drawdown of the water table. There are only about 30 wells currently used in Toano Draw, all for stock watering purposes (Figure 4-1). Of these, approximately 10 may be significantly affected by pumping because of their proximity to the proposed wellfields.

In the Montello area, there are many more wells currently in use, mainly for irrigation and stock watering purposes (Figure 4-1). The magnitude of the effects of drawdown on existing wells will vary for each water development option described below.

10.5.1 Effects of Option 1 on Existing Wells

Drawdowns created by the Option 1 wellfields will primarily affect existing stock watering wells in the south-central and northern portions of the Toano Draw Subbasin. The groundwater flow model simulates that after 47 years of pumping there will be a maximum of about 20 feet of drawdown in the south-central portion and about 100 feet of drawdown on the northern portion of Toano Draw, near the confluence with Thousand Springs Creek.

Thus there will be significantly increased pumping lifts created for the few stock wells located in these areas. A few of the wells located near the proposed wellfields (e.g., 39-65-14cd) may become dry because they are completed at shallow depths. However, most of the 10 stock wells that would be affected appear to be completed to sufficient depths and would remain usable assuming the existing pumps would be lowered or modified to accommodate the additional lift requirements.

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In the Montello area, the effects of Option 1 pumping would probably be insignificant. The current rate of groundwater pumping for irrigation use exceeds the amount that would be supplied to the plant from this area, and it is anticipated that irrigation pumpage will be curtailed to meet project needs.

10.5.2 Effects of Option 2 on Existing Wells

The effects on wells in the Toano Draw Subbasin as a result of pumping would be less for Option 2 than for Option 1. Drawdowns of the water table in the south-central portion of the Toano Draw Subbasin were predicted by the numerical flow model to be a maximum of about 60 to 70 feet. Thus, the few existing stock wells in this area would have increased pumping lifts but these additional lifts would not be as large as for Option 1 pumping.

In the Montello area, there would also be increased pumping lifts, and thus somewhat higher pumping costs, created by groundwater supply Option 2. The analytical flow modeling conducted for this area predicts that up to about 30 to 35 feet of drawdown may occur after 35 years in areas 3 to 5 miles north of the town of Montello.

Essentially all of the wells that may be affected in this area are those currently owned by Lands of Sierra, Inc. and operated for irrigation or stock watering purposes.

10.5.3 Effects of Option 3 on Existing Wells

Option 3 would create an intermediate level of effects on existing water supply wells. In the Montello area, these effects would be similar to the effects of Option 2, but slightly less in magnitude, whereas, the effects would be significantly greater than those of Option 1. In the Toano Draw Subbasin, the effects of Option 3 would be somewhat greater than Option 2 but substantially less than for Option 1.

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10.6 EFFECTS ON WATER QUALITY

10.6.1 Surface Water

The quality of surface water that occurs in the Thousand Springs Basin may be impacted by water resource development. Unless appropriate water management practices are implemented as mitigation measures, the potential reduction in flow from springs and in Thousand Springs Creek could allow for increased evaporation of remaining water and subsequent increases in the total dissolved solids (TDS) of the water. The water may become oversaturated with respect to minerals (especially carbonates, sulfates, and chlorides), that may then precipitate from solution. These minerals will then be present on the land surface or in the shallow soil and will affect the water chemistry of fresh surface water emanating from a spring or moving down the stream channel. Increases in dissolved constituents in the water may affect the usefulness of the water. Currently, much of the springwater has a total dissolved solids (TDS) level of less than 500 mg/L, which is the recommended maximum concentration for TDS specified in the EPA secondary drinking water standards. Evaporation of the water could raise the TDS above this level. Furthermore, evaporation may preferentially increase the sodium level of the water because other major cations will be removed from solution as minerals containing those cations are formed. An increase in dissolved sodium will affect the usefulness of the water for irrigation purposes because moderately high levels of sodium in the water causes clay minerals in the soil to expand, thereby lowering the permeability of the soils.

The degree to which surface water quality may be affected by water resources development can be estimated for the various groundwater withdrawal scenarios by considering the resultant discharges to the creek for the different water development options. The three options were simulated, based on application of groundwater flow models (Cases 1, 2, and 3) and are described in Section 8.0. The results are presented in Table 8-4. For Option 1, in which water for the first five units is obtained from the

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Toano Draw Subbasin, and water for the remaining units is obtained from wells downstream of Twentyone Mile Dam, the Case 1 simulation shows a considerable reduction in groundwater discharge to the river upstream of Twentyone Mile Dam. The baseline discharge of 4149 acre-feet/year is reduced to 340 acre-feet/year after 20 years of plant operation and to less than 20 acre-feet/year for the subsequent 17 years that were modeled. These low flows would lead to increases in dissolved solids levels because of increased evaporation effects. Under these conditions, mineral precipitation from the water is likely to occur, and it will probably influence the concentration of dissolved constituents in fresh surface water that contacts these minerals. These effects will be concentrated along Thousand Springs Creek north of the Toano Draw Subbasin because most of the water is being withdrawn from this Subbasin. The wellfields below Twentyone Mile Dam and in Montello Valley may also affect surface water quality in those areas. However, effects in these areas would be minimal assuming that present diversions for irrigation would be ceased.

For Option 2 the amount of groundwater obtained from the Toano Draw Subbasin is less than for the two other options considered, and as a result there is the least reduction in discharge to Thousand Springs Creek with this option. Based on the Case 2 simulation, the discharge is reduced by a maximum of 40 percent of the baseline value throughout the 49-year timeframe assumed for the modeling. Therefore, it is less likely that this distribution of wellfields will have as large an impact on surface water quality near the Toano Draw Subbasin as that for Option 1. However, because five of the eight units will be supplied from wellfields located in Montello Valley in Option 2, surface water quality in Montello Valley will be affected more by groundwater withdrawal in this area then by implementation of the other two options evaluated. That is, unless mitigation measures are implemented to increase streamflow by timely releases of water from reservoir storage, there would be significant increases in salinity of the surface water as a result of implementing Option 2 for Units 3 through 7.

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For Option 3, the model-predicted discharge to Thousand Springs Creek near Toano Draw is slightly smaller, although very similar, to that simulated in Case 2. Therefore, it is expected that the effects on surface water quality of Option 3 wellfield distribution will be similar to development according to Option 1, in areas along Thousand Springs Creek near Toano Draw. Option 3 would probably have less of an adverse effect on surface water quality in Montello Valley than Option 2.

10.6.2 Groundwater

The apparent chemical stability of the groundwater as shown by comparing samples spatially (Section 5.5.1) and temporally (Section 5.3) suggests that groundwater that is drawn into pumping wells for the plant will have a fairly uniform composition. In addition, future recharge water that enters the system in the highlands should have a composition similar to the past composition and should not alter groundwater chemistry significantly. However, the quality of recharge water entering the aquifer through Thousand Springs Creek may be affected by the placement of the well fields. As discussed above in Section 10.6.1, Option 1 would significantly reduce discharge to the creek after about year 10 in the development schedule. This may possibly result in higher levels of total dissolved solids in surface water in the creek in the areas north of the Toano Draw Subbasin and downstream thereof. Because the creek would be a greater source of groundwater recharge under these pumping conditions, it is likely that the TDS level of the groundwater near the creek will increase locally by implementing Option 1.

Because of the wider geographic distribution of wellfields for Options 2 and 3, they will probably not have a large-scale impact on groundwater quality in the Toano Subbasin. However, the TDS levels in groundwater in the Montello area may increase as a result of implementing Option 2 or 3, unless the potential salinity increases in the creek during the dry season are precluded by timely releases of water from Crittenden and Twentyone Mile Reservoirs.

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The drawdowns of the water table for the three evaluated cases were discussed in Section 8.0. In general, it is expected that none of the wellfield distributions will produce a decline in water level of greater than about 100 feet. In most areas the drawdowns would be much less. Although few data are available on the changes in groundwater chemistry with depth in the aquifer, it is doubtful that drawdowns of this magnitude will produce significant changes in the quality of water pumped from the production wells. It is anticipated that these wells will be screened over intervals of several hundred feet; therefore, the mixing of water from throughout these depths in the aquifer will probably result in a fairly uniform water composition for the duration of the project.

In the case of shallower domestic or ranch wells, it is possible that lowering the water table will result in the production of water of higher TDS and somewhat different quality. This is because there will be less mixing of water in these wells that are screened over a shorter distance than the power plant production wells. The deeper, warmer water will form a larger fraction of the pumped water as the water table declines. Because of its higher temperature and probable longer residence time in the alluvium, the deep groundwater is expected to have reacted more completely with the aquifer material and thus contain a higher concentration of dissolved constituents. As drawdown occurs in the aquifer, more of this deeper water may be drawn into the wells.

10.7 SUBSIDENCE

Based on the available hydrogeological data, land surface subsidence does not appear to be a potentially significant effect that may result from the proposed groundwater withdrawals. In many areas where significant subsidence of the land surface has accompanied extensive groundwater withdrawals, groundwater level declines usually exceed 50 feet and the basic cause of the subsidence is an increase in the effective stress on the

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fine-grained, compressible materials within the aquifer. Because of the isolated and distant locations of the proposed wellfields, with drawdowns being most pronounced in the area of the wellfields, the potential effects of land surface subsidence on the existing environment would not appear to be significant. Even though the water table under the plant site may be drawn down tens of feet, and there may be some slight surface subsidence in the area of the power plant, the subsidence is expected to be essentially uniform over the area of the plant site.

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11.0
HYDROLOGIC MONITORING PROGRAMS

11.1 APPROACH AND RATIONALE

The preceding sections of this report have discussed the geology of the Thousand Springs Basin, presented an assessment of the quantity and quality of the water resources of the Basin, a general plan for developing the water resources to meet the requirements of the proposed Thousand Springs Power Plant as they will increase over time, and an assessment of the effects of utilizing the resources on the surface and groundwater flows in the Basin. However, it is recognized that the data base from which the water resource assessments of this study were developed is limited, and the projected effects of project water uses are estimates based on the presently available information. The estimates indicate that the planned groundwater withdrawal rates are significantly less than the long-term sustainable yield of the Basin as a whole. However, the proposed development plan is based on utilizing essentially all of the renewable resources of the Toano Draw Subbasin aquifer to provide water for up to three of the planned eight units at ultimate project development. Monitoring will be required to improve the estimates of the resources available from the Toano Draw alluvial aquifer to make sure that no overdraft situation occurs. The transfer of water from the Montello-Crittenden Subbasin to the Toano Draw Subbasin for the balance of the project water requirement will be planned and implemented so as to prevent any overdraft from the Toano Draw aquifer.

This section presents a proposed long-term program to monitor the natural hydrologic events in the Thousand Springs Basin, and the induced

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hydrologic effects of the power plant water uses. Specifically, the objectives of the proposed monitoring program are as follows:

- Precipitation will be monitored at selected sites, and the extent to which seasonal precipitation in the Basin deviates from the estimated long-term averages used in this study will be recalculated.

- Streamflow will be measured at selected sites to significantly extend the record base for estimating the available surface water resources and to provide a basis for re-assessing the project's effect on streamflow.

- Project water uses will be monitored by measuring the quantity of water pumped from each project well, as required by the State Engineer and the conditions specified in the permits for the water rights granted for the project.

- Groundwater levels will be measured in selected wells to determine the effect of groundwater withdrawals by the project.

- Possible changes in land surface elevation in areas overlying the aquifers supplying water to the project will be periodically checked for possible subsidence caused by project water withdrawals.

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11.2 PRECIPITATION

Sierra Pacific Resources has installed and is operating a meteorologic monitoring station adjacent to the power plant site. It is planned that the station will continue operations throughout the life of the power plant, in order to monitor precipitation and other meteorological parameters. It is expected that the existing precipitation monitoring

stations at Montello and Wells, which are both within the National Oceanographic and Atmospheric Administration (NOAA) network, will be continued in operation as at present. Collectively, the three stations are expected to provide an adequate record of precipitation and precipitation trends in the power plant vicinity. Data from the Thousand Springs meteorological station will be of a quality and frequency suitable for incorporation in the records presently compiled and published by NOAA.

11.3 PROJECT GROUNDWATER EXTRACTION

All wells completed to supply water for power plant related uses will be equipped with flow meters. The meters will be of the flow indicating and totalizing type. Meters will be calibrated at the time of initial installation and will be recalibrated on approximately an annual basis. If a meter must be removed for servicing, calibration, or replacement, the well will not be operated until a meter has been reinstalled in the well discharge pipeline. A record will be maintained of total monthly and annual pumpage from each well, and copies of the record will be provided annually to the State Engineer.

11.4 STREAMFLOW

Streamflow in Thousand Springs Creek will continue to be monitored throughout the operating life of the power plant at the Wilkins, Shores, and Montello stations. Those stations are being operated under a cooperative program between the USGS and Lands of Sierra, Inc.

Present expectations are that project-induced changes in streamflow may occur downstream from the confluence of Crittenden and Thousand Springs Creeks as a result of power plant groundwater withdrawals. Therefore, it is proposed that an additional streamflow gaging station be installed on Thousand Springs Creek downstream from the confluence with Crittenden Creek, possibly at the upstream side of the existing County Road crossing

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of Thousand Springs Creek. All flow in the creek is confined to a single channel at this location, whereas both upstream and downstream from this point the flow occasionally may be in two or more channels. It is proposed that the station be operated under the same cooperative agreement between the USGS and Lands of Sierra, Inc. as the three existing stations mentioned above.

11.5 WATER LEVELS IN WELLS AND SPRING DISCHARGE

The water surface elevation of aquifers being pumped for project purposes will be monitored to track the aquifer responses to the pumping. The proposed monitoring network will include wells pumped for the project, nearby monitoring wells that have been installed for the purpose, or selected other existing wells within the expected areas of drawdown due to the pumping (Figure 4-1). Also, selected springs that may be affected by the project water withdrawals will be periodically checked. Measuring the water table elevation in all selected monitoring wells and checking the condition of selected springs should be performed annually, preferrably in late summer.

11.6 SURFACE AND GROUNDWATER QUALITY

The chemistry of the water being pumped from each project water supply well will be checked periodically in order to evaluate the continued stability of the water quality for plant use, and to provide a more comprehensive understanding of the water chemistry of the groundwater system. By monitoring water chemistry it may be possible to anticipate potential problems in plant operations due to changes in water chemistry.

The surface water chemistry is so variable in the region that general monitoring is considered not warranted.

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11.7 SUBSIDENCE

A network of surveyor monuments (bench marks) should be established over the areas of anticipated greatest groundwater level drawdowns, for purposes of monitoring possible changes in the land surface elevation due to water extraction for the power plant. Elevations of the bench marks should be checked annually. It is proposed that the network include two lines of monuments, incorporating as many existing monuments as reasonably possible. It is noted that monuments have been set at numerous section corners in the project vicinity, and some of those monuments could appropriately be included in the subsidence monitoring network. The monument lines would be tied to control monuments based in rock outcrops, where no project induced subsidence is expected. The lines' configurations would be determined by the Engineer after geotechnical evaluations have been completed.

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12.0
RECOMMENDATIONS

This section presents recommendations for performing additional water resources investigations in the Thousand Springs Basin, as required for final design and development of wellfields to supply the Thousand Springs Power Plant. Recommendations are also presented for other investigative work that is required for developing a more detailed understanding of the Basin hydrogeology, and for early perception of the effects of using the Basin water resources. Finally, recommendations are given for the preparation of a water resources management and monitoring plan and program that will be consistent with the proposed action, as detailed in this report and described in the project Environmental Impact Statement.

In preparing this section it was assumed that the water supply for the individual generating units will be obtained from wellfields developed in accordance with the following schedule. The general outlines of the areas where the wellfields will be located are indicated on Figure 7-1.

Generating Unit	Planned Location of WellField
1	Toano Draw south of plant site
2	Toano Draw south of plant site OR, Toano Draw northwest of plant site
3 through 7	Thousand Springs Valley, downstream from Crittenden Creek and extending to near Dake Reservoir
8	Toano Draw south of plant site OR, Toano Draw northwest of plant site OR, Thousand Springs Valley extending the wellfield for Units 3 through 7

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12.1 PROPOSED HYDROGEOLOGIC INVESTIGATIONS FOR WELLFIELD DEVELOPMENT

The investigations on which this report is based were generally at the reconnaissance level, as required for obtaining an overall general understanding of the magnitude and locations of the water resources present in the Thousand Springs Basin, and the general characteristics of the aquifers containing the groundwater resources. Further investigation will be required to select specific locations for installing wells and to design the well to be installed at each selected location. The recommendations for conducting this investigation are presented in this subsection. The primary objectives of the investigation will be to further characterize aquifer transmissivity, specific yield, and thickness at each of the two primary wellfield locations identified in this study as most favorable for development based on indicator aquifer characteristics and environmental considerations (i.e., Toano Draw south of the power plant site, and Thousand Springs Valley below Crittenden Creek). If the Toano Draw wellfield south of the plant site proves to be less productive than presently expected, then the area northwest of the plant site (outlined on Figure 7-1 as a potential wellfield location) should be considered as an alternative for supplying either Unit 2 or Unit 8.

1. Surface Geophysical Surveys -- Toano Draw

It is proposed that surface geophysical surveys be conducted within the outlined area (Figure 7-1) south of the power plant site in Toano Draw. This area is located about 1 to 5 miles south of the plant site and has dimensions of approximately 4 miles by 6 miles. In the recently completed reconnaissance survey, two surface geophysical survey techniques were tested, i.e., time domain electromagnetic [TDEM] and dipole-dipole resistivity. Both techniques provided useful information, of differing characteristics, for locating potential aquifer materials. Therefore, it is proposed that both techniques be utilized again, in a complementary fashion, in the survey. As a first phase investigation, about 4 lines of

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TDEM soundings would be run, spaced at about 1.5 miles between lines, and extending across the outlined area in a northwest-southeast direction. Based on interpretation of the data from the TDEM soundings, subsequent dipole-dipole surveys would be run along selected lines.

2. Pilot Borings

Based on careful review and interpretation of the surface geophysical survey results, locations and target depths for a series of pilot borings would be selected. Locations would be selected based on their appearing most favorable for placing wells. The exact number of borings actually completed in the initial boring program would depend, to large extent, on the materials encountered in the first group (Phase I) of borings completed. If the correlation between the materials predicted by the surface geophysical results and the recovered pilot boring materials, and downhole geophysical logs from the completed borings, was consistently high, and the materials had good aquifer properties, then the Phase I boring program probably would require only a few borings. In any case, enough borings should be completed in the first phase program to be relatively confident that wells which were completed in the more favorable identified locations would have a combined capacity adequate for the maximum requirement of the first generating unit - probably about 3000 gpm. The second phase (Phase II) boring program could then be deferred until well locations were to be identified for supplying the second generating unit. It is expected that some or all pilot borings would be completed either as aquifer monitoring wells or as pilot holes for production wells. The geophysical and geological data obtained from the drill holes, together with the data from the surface geophysical investigations, would be used to define trends in aquifer characteristics that would be used to select favorable production well locations.

During drilling of the first few pilot borings several undisturbed soil samples should be collected from various depths below the water table. The samples should be submitted for laboratory analyses. In order to provide

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measures of aquifer specific yield, the laboratory should test the samples for saturated, drained, and dry density. It is noted that an aquifer specific yield of 0.10 was assumed in this evaluation. Although this value is believed to be conservative, it should be checked because of its importance in estimating the quantity of water removed from aquifer storage in order to develop the required sustained production of the wellfield. Also, the samples should be tested for consolidation/compressibility, and the data used to prepare estimates of subsidence likely to occur as a result of groundwater level drawdown.

3. Well Drilling, Completion, and Development Program

Following completion of the Phase I pilot boring program and detailed review of the geophysical and boring program results, the well drilling program for the first generating unit should be initiated. This program would start with selecting locations for wells and preparing preliminary well completion plans for each well in the program. Completion details to be specified in the preliminary plans would include the boring diameter, total boring depth, surface seal requirements, and casing size. Estimates of depth to water and approximate lengths and locations of screened intervals should be included in the preliminary design. The final design for the well would be based on the lithology encountered in the well boring, and would specify the well screen slot size and screened intervals, the gradation and location of the gravel pack, and a pump setting depth for the test pumping that would follow well development. Well development would be continued until the well produced water that was clear and free of drilling mud and fine formation materials. An aquifer test would be performed on each completed well, with the pumping rate for the test based on the results of a step drawdown test, and the test's duration in the range of 3 to 15 days, as specified by the Engineer following well development. The pilot boring stratigraphic logs, and geophysical logs of those borings, together with data to be collected during aquifer testing, would be used to further characterize the aquifers investigated. Of particular interest would be additional information on aquifer thickness

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and aquifer transmissivity as it varied with depth. The data on aquifer characteristics, from all of the wells tested, would be used to develop a numerical model (Section 12.2) of the aquifer and to reassess the probable aquifer drawdown that would result from pumping the aquifer at various rates to supply water to the power plant. Also, the data from each well tested would be used for specifying the capacity, setting depth, and lift of the production pump to be installed in the well.

It is expected that the planned wellfield south of the power plant site could be expanded to serve two, and possibly three, generating units, and that to expand the wellfield would simply require doing more pilot borings at locations identified in the original area geophysical surveys. Wells to supply the additional units would be installed at selected locations based on the results of the pilot boring program. However, if that wellfield is less productive than presently expected, then the potential wellfield area located northwest of the power plant site should be investigated and developed. The procedures to be followed would be similar to those described above, but modified as appropriate to take advantage of the hydrogeological information obtained and experience gained in the area south of the plant site.

4. Wellfield Development North of Montello

There presently are several irrigation wells within the area north of Montello, which is outlined on Figure 7-1 as a potential wellfield. The combined capacity of those existing wells significantly exceeds the requirements of at least one generating unit. It is suggested that the first step in obtaining water for the power plant from this area would be to thoroughly explore the potential for using existing wells to supply the power plant, and exploit that potential insofar as is feasible from environmental and economic perspectives. After this potential has been fully realized, and when additional water is required for the power plant, then a hydrogeologic investigation should be performed of the overall area likely to be required for the ultimate wellfield. The procedures of

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investigation and wellfield development would be similar to those described above for the Toano Draw wellfields, but modified as appropriate based on experience in Toano Draw and on the known differences in aquifer and geologic characteristics between the two areas.

12.2 GROUNDWATER FLOW MODELING

The existing numerical model should be expanded to include the Montello area. Also, a numerical flow model of the south Toano Draw area should be developed, incorporating the results of the drilling and testing program recommended above in conjunction with developing a wellfield to supply Unit 1. The larger more detailed model would provide a better understanding than presently possible of the overall long-term effects of the project water withdrawals.

12.3 HYDROGEOLOGIC MONITORING

It is recommended that the hydrologic monitoring program described in Section 11.0 be initiated after approval of the program - modified as appropriate - is received from the Nevada State Water Engineer. Of particular importance is continuation of the existing cooperative program between the USGS and Lands of Sierra, Inc. for monitoring flows in Thousand Springs Creek.

The possible benefits of monitoring precipitation at the higher elevations on the mountains draining to the Thousands Springs Basin, particularly Toano Draw, should be reassessed. The data would be used to prepare estimates of runoff from the highlands area, and aquifer recharge from runoff flowing across the broad alluvial valley of Toano Draw.

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12.4 WATER MANAGEMENT PLAN

A basin-wide water management plan should be developed in conjunction with other users. The plan should address criteria for progressively reducing the amount of water used for irrigation. The objective would be to have the reductions occur in such a way that there would be no significant environmental effects in or along Thousand Springs Creek upstream from the confluence with Crittenden Creek throughout the duration of power plant operations; the effects downstream from Crittenden Creek would be limited to the maximum practical extent. Also, the plan should address criteria relating aquifer drawdown to planned responses. For example, if the drawdown is significantly different from the predicted drawdowns, either locally or area wide, it probably would be appropriate to modify the manner or the amount the aquifer is being pumped. The extent to which the plan anticipates realistic contingencies will be its measure of success.

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Table 3-1. SUMMARY OF RESISTIVITIES OF LITHOLOGIC UNITS

Resistivity Range	Depth Range	Lithology
30-200 ohm-m	0-150 feet	Holocene unsaturated alluvium, not well defined in TDEM data.
15-30 ohm-m	Near surface to several hundred feet	Coarse-grained alluvial deposits, interpreted to be the potential regional aquifers, although they may locally contain large percentages of clay; further subdivided into two units on the interpreted profiles.
8-15 ohm-m	Near surface to several hundred feet, often seen below the 15-30 ohm-m unit	Predominantly clays and interbedded alluvial fan deposits, probably gradational with the 15-30 ohm-m unit, also more clay-rich.
<8 ohm-m	Several hundred to several thousand feet	Upper tuffaceous volcanic unit, predominantly clays, possibly saturated with saline waters.
>200 ohm-m	Variable	Paleozoic or older bedrock, observed by only a few soundings, mostly near the basin margins.
50-200 ohm-m	Relatively thin layers, buried a few hundred feet	Possible thin Tertiary volcanic unit suggested by TDEM data at some sites, not the same unit as the one shallow unit of similar resistivity.

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Table 4-1. CONSTRUCTION DETAILS OF MONITORING WELLS AND TEST WELLS INSTALLED BY WCC

Well Number	Location	Total Boring Depth (feet)	Total Well Depth (feet)	Well Casing Diameter (inches)[1]	Screen Interval (feet)	Ground Surface Elevation (MSL)	Top of Casing Elevation (MSL)	Ground-water Elevation (MSL)[2]
TW-1	T42N, R65E, Sec 35	330	315	6	60-100 140-150 160-170 190-260 285-295	5386	5388.3	5385.3
TW-3	T39N, R66E, Sec 5	415	410	12	200-260 290-360 380-390	5710[4]	--[4]	5517.5
TW-12	T41N, R66E, Sec 31	370	370	6	170-270 280-310 330-360	5595	5596.4	5471.2
TW-14	T39N, R65E, Sec 24	600	508		380-490	5831	5832.4	5516.6
TW-15	T39N, R66E, Sec 9	425	415	6	275-395	5721	5722.9	5510.9
MW-1	T42N, R65E, Sec 35	540	200	2	180-200	5385	5387.1	5385.5
MW-2	T40N, R65E, Sec 23	607	310	2	270-290	5663	5664.2	5484.3
MW-3	T39N, R66E, Sec 5	947	319	2 1.25	299-319 160-180	5713[4]	--[4]	5517.8
MW-4	T41N, R65E, Sec 21	390	95	2	75-85	5491	5491.8	5457.0
MW-5[3]	T39N, R65E, Sec 27	286	--	--	--	5927	--[4]	--
MW-6[3]	T42N, R66E, Sec 19	526	--	--	--	5376	--[4]	--
MW-7[3]	T41N, R66E, Sec 21	160	--	--	--	5784	--[4]	--
MW-12	T41N, R66E, Sec 31	601	300.5	2 1.25	280.5-300.5 130-150	5594 5594	5595.2 5595.2	5470.2 --[5]
MW-16	T40N, R67E, Sec 8	600	320	2	300-320	5750[4]	--	--
MW-17	T41N, R65E, Sec 35	650	260	2	230-250	5515[4]	--	5465.0

1 The TW-series wells are constructed with threaded and coupled Schedule 40 steel casing. The MW-series wells are constructed with flush-threaded Schedule 80 PVC casing.
2 Water levels measured by Woodward-Clyde Consultants August, 1988 to March, 1989.
3 Borehole abandoned by backfilling with cement grout.
4 Elevation not surveyed at time of report.

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Table 4-2. SUMMARY OF AQUIFER TEST RESULTS

Test Well	Well Observed	Transmissivity (gpd/ft)	Hydraulic Conductivity[a] (gpd/ft^2)	Storage Coefficient (dimensionless)	Data Used
TW-1	TW-1	8000	57	1.2×10^{-4}	pumping phase
	TW-1	6000	43	NA	recovery phase
	MW-1	7400	53	4.2×10^{-4}	pumping phase
TW-3	TW-3	2100	15	NA	pumping phase
	MW-3	3000	21	1.3×10^{-3}	pumping phase
	MW-3	2800	20	NA	recovery phase
TW-12	TW-12	21,400	133	NA	pumping phase
	TW-12	20,900	131	NA	recovery phase
	MW-12	18,900	118	3.5×10^{-4}	pumping phase
TW-14	TW-14	13,200	132	4.8×10^{-4}	pumping phase
	TW-14	10,300	103	NA	recovery phase
TW-15	TW-15	52,800	440	3.8×10^{-4}	pumping phase
	TW-15	48,000	400	NA	recovery phase
41-65-35ad	MW-17	54,000	250	4.7×10^{-3}	pumping phase
		39,300[c]	180	2.7×10^{-3}	pumping phase
		34,400	160	NA	recovery phase

NA = Not analyzed

[a] Hydraulic conductivity was calculated by dividing the average transmissivity by the length of well screen below the water table in the pumping well. The well screen fully penetrated the aquifer in each case.

[b] Hydraulic conductivity was calculated by dividing the average transmissivity by the estimated total thickness of coarse-grained aquifer material penetrated by well MW-17 (b = 214 ft)

[c] Transmissivity was calculated based on distance-drawdown analysis at t = 8700 min.

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Table 4-3. SUMMARY OF LAB TESTS OF EFFECTIVE POROSITY

Sample Depth (ft)	Grain Density (g/cc)	Calculated Overburden Stress (psi)	Effective Porosity	
			At Estimated Overburden Stress	At 500 psi Stress
208-218	2.56	144	35.2	30.7
238-248	2.55	170	37.6	34.5
268-278	2.55	195	36.2	33.5
298-308	2.54	220	35.6	33.0
328-338	2.53	244	35.7	33.6

Source: Western Atlas International Core Laboratories

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Table 4-4. SUMMARY OF TRANSMISSIVITY AND SPECIFIC CAPACITY DATA

Well Designation	Average Transmissivity (gpd/ft)	Specific Capacity (gpm/ft)
TW-1	7,000	3.80
TW-12	21,175	8.20
TW-14	11,765	6.80
TW-15	50,400	29.30
TW-3	2,150	3.03
41-65-35bd	11,000	6.30
40-69-27ba	160,000	68.00

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Table 4-5. IRRIGATION WATER USE BY STREAM REACH

Location and Type of Use	Area (ac)	Net Water Use (ac-ft/ac)	Net Water Use (ac-ft)	Application Efficiency (Percent)	Water Applied (AC-FT)	Water Source
1. Montello to Crittenden Creek (Inclusive)						
A Native Pasture						
Rocky Ford #4	108	1.43	154	30	513	TSC
Upper Gamble #3	254	1.43	363	30	1210	TSC
Dake & Warm Springs	1000	1.91	1910	30	6367	TSC[a]
	1362			2427		8090
B Improved Pasture						
Crittenden #6, 7, 8	107	1.53	164	50	328	TSC
Gamble Ranch #1, 2	743	1.53	1137	50	2274	TSC
	850		1301		2602	
C Alfafa Haylands						
Gamble Farm #1 through #18	1448	2.21	3200	50	6400	Wells
12-Mile #19	68	2.21	150	50	300	Spring
12-Mile #21	120	2.21	265	50	530	Wells
12-Mile #24, 25	63	2.21	139	50	278	Crit. Res.
	1699		3754		7508	
Subtotal, Reach #1	3911		7482		18,200	
2. Crittenden Creek to 21-Mile Dam						
A. Native Pasture						
21-Mile #11	187	0.95	178	30	593	TSC
18-Mile #16	236	0.95	224	30	747	TSC
	423		402		1340	

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Table 4-5. IRRIGATION WATER USE BY STREAM REACH (concluded)

Location and Type of Use	Area (ac)	Application Net Water Use (ac-ft/ac)	Application Net Water Use (ac-ft)	Water Efficiency (Percent)	Applied (ac-ft)	Water Source
B. Improved Pasture						
18-Mile #12 through #15	304	1.53	465	50	930	TSC
C. Alfafa Haylands						
12-Mile #22, 23	314	2.21	694	50	1388	Wells
			7482			
Subtotal, Reach #2	1041		1561		3658	
			9043			
3. 21-Mile Dam to Shores						
A. Native Pasture						
9-Mile #9	442	0.95	420	30	1400	TSC
Eccles #10	433	0.95	411	30	1370	TSC
Subtotal, Reach #3	875		831		2770	
4. Upstream of Shores						
A. Native Pasture						
9-Mile #8	172	0.95	163	30	543	TSC
B. Improved Pasture						
Brush Creek	349	2.04	712	50	1424	Brush Creek
Winecup #1 Through #7	2191	2.04	4470	50	8940	TSC
	2540		5182		10,364	
Subtotal, Reach #4	2712		5345		10,907	
Total, Reaches #1 Through #4	8539		15,219		35,535	

Source: Soil Conservation Service, Elko, Nevada.
(a) Includes subirrigation by shallow groundwater.

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Table 5-1 Sierra Pacific Spring and Well Water Analyses

	1	2	3	4	5	6	7	8	9	10
	Pequop Spring	Tripon Pass Spring	Brush Creek Spring	Ledge Spring	Unnamed Spring	Indian Spring	Hot Spring	Unnamed Spring	Black Rock Spring	Emigrant Spring
	38-65-10	39-64-14	40-64-21	40-63-21	40-63-18	40-65-6	41-64-25	41-64-26	42-65-6	44-69-30
Location Symbol on Figure 5-1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
FIELD PARAMETERS										
pH	8.31	6.76	7.59	6.73	7.38	7.21	6.41	7.59	7.39	7.66
Temperature (degrees C)	14.5	9	18	16	14	13.1	60.9	9.3	11.9	15
Specific Conductance(umhos/cm)	390	1750	320	40	308	280	1650	340	430	290
Alkalinity as CaCO3(mg/L)	206	460	184	23.6	278(202)	130	431	213	240	135
MAJOR CATIONS (mg/L)										
Calcium	65	334	49	7.5	50	30	70	68	88(88)	41
Magnesium	13	241	20	0.8	20	16	16	18	23(24)	9.6
Sodium	26	33	7.2	1.9	6.9	23	104	20	5.3(5.3)	19
Potassium	6	<5.0	<5.0	<5.0	<5.0	<5.0	34	<5.0	<5.0(<5.0)	6
MAJOR ANIONS (mg/L)										
Chloride	20	120	7	4	6	24	21	13	10(10)	10
Sulfate	12	674	23	4	30	25	46	31	57(57)	35
Nitrite as N	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01(<0.01)	<0.01
Nitrate as N	0.7	<0.05	0.15	0.53	<0.05	0.36	<0.05	0.09	0.63(0.61)	<0.05
Fluoride	0.3	0.8	0.1	<0.1	0.4	0.4	1.8	0.2	0.2(0.2)	0.7
TRACE/MINOR INORGANICS (mg/L)										
Antimony	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1(<0.1)	<0.1
Barium	0.035	0.01	0.18	0.087	0.11	0.094	0.3	0.13	0.045(0.041)	0.092
Boron	0.07	0.1	0.03	<0.02	0.06	0.05	0.49	0.06	<0.02(<0.02)	0.05
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005(<0.005)	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01(<0.01)	<0.01
Copper	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006(<0.006)	<0.006
Iron	<0.05	4.7	<0.05	<0.05	0.45	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Lithium	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.54	<0.02	<0.02(<0.02)	0.05
Manganese	<0.005	1	<0.005	<0.005	0.15	<0.005	0.079	<0.005	<0.005(<0.005)	<0.005
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.002	<0.0002	<0.0002	<0.0002	<0.0002(<0.0002)	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	N.D.	<0.2	<0.2	<0.2	<0.2(<0.2)	<0.2
Silicon (Si)	14	8.6	6.3	4.4	5.7	8.6	31	12	5.2(5.2)	9
Silica (SiO2)	30	18	13	9.4	12	18	66	26	11	19
Silver	<0.005	<0.0057	<0.005	0.005	<0.005	<0.005	<0.0073	<0.005	<0.005(<0.005)	<0.005
Zinc	0.06	4.7	0.01	0.18	<0.01	<0.01	<0.01	<0.01	0.13(0.13)	<0.01
TOTAL DISSOLVED SOLIDS (mg/L)	344	2140	103	8	173	193	515	280	361(352)	1110
ION BALANCE (%)	5.6	18.1	2.6	21	2.1	0.64	0.5	3.6	2.7(2.7)	1.6
STABLE ISOTOPES										
Delta-D (0/00)	ND	ND	ND	ND	-129	ND	-137	-127	ND	ND
Delta O-18 (0/00)	ND	ND	ND	ND	-17.3(-17.4)LD	ND	-17.8	-16.9(-17.0)LD	ND	ND
TRITIUM (tritium units)	ND	ND	ND	ND	-0.03	ND	1.36	1.81	ND	ND

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Table 5-1 Sierra Pacific Spring and Well Water Analyses

	11	12	13	14	15	16	17	18	19	20	21
	Crittenden Spring	Gamble Spring	Near Montello Spring	North Spring	Lewis Spring	MW-1	MW-2#	TW-3	MW-4	TW-12	TW-14
	42-69-8	40-69-8	39-68-8	39-67-10	39-67-15	42-65-35	40-65-23	39-66-5	41-65-21	41-66-31	39-66-24
Location Symbol on Figure 5-1	S11	S12	S13	S14	S15	MW-1	MW-2	TW-3	MW-4	TW-12	TW-14
FIELD PARAMETERS											
pH	7.84	7.87	7.69	7.5	7.52	8.77	ND	7.44	8.1	7.22	meter down
Temperature (degrees C)	16	21	9.7	10.5	11.8	21.5	ND	14.5	ND	17	22
Specific Conductance(umhos/cm)	330	365	350	350	580	390	ND	215	ND	235	240
Alkalinity as CaCO3(mg/L)	160	171	211	300	215	206	158	130	214	129	120
MAJOR CATIONS (mg/L)											
Calcium	50	49	65	70	78	25	42	34	34	30	30
Magnesium	15	19	21	18	36	8.5	10	5.7	16	11	9.7
Sodium	10	9.4	17	14	46	83	53	18	59	17	15
Potassium	<5.0	<5.0	<5.0	<5.0	< 5	7	<5.0	8	18	5	7
MAJOR ANIONS (mg/L)											
Chloride	16	12	19	20	20	8	64	3	17	7	12
Sulfate	28	32	40	19	34	36	65	17	46	17	19
Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.76	<0.01
Nitrate as N	0.64	0.21	0.41	0.88	0.43	<0.05	0.37	0.41	<0.05	<0.05	0.81
Fluoride	0.3	0.2	0.2	0.2	0.4	2.2	0.4	0.4	ND	0.4	0.4
TRACE/MINOR INORGANICS (mg/L)											
Antimony	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	ND	<0.1	<0.1
Barium	0.089	0.11	0.075	0.11	0.045	0.027	0.049	0.039	ND	0.092	0.073
Boron	0.04	0.06	0.04	0.04	0.14	0.25	0.18	0.06	ND	0.07	0.06
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Copper	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	ND	<0.006	<0.006
Iron	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	0.12	<0.05	0.08
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Lithium	<0.02	<0.02	<0.02	<0.02	0.03	0.03	0.03	<0.02	ND	<0.02	<0.02
Manganese	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.014	0.01	0.01	0.016	0.01
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	ND	<0.0002	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.002	0.004	<0.2	ND	<0.2	<0.2
Silicon (SI)	11	7.1	6.2	6.6	9.7	30	18	38	35.5	28	35
Silica (SiO2)	24	15	13	14	21	64	39	81	76	56	75
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Zinc	<0.01	<0.01	0.01	0.08	0.13	<0.01	<0.01	<0.01	ND	0.09	0.11
TOTAL DISSOLVED SOLIDS (mg/L)	228	224	304	285	327	376	421	240	ND	187	229
ION BALANCE (%)	0.6	1.8	0.87	12	3.8			1.3	ND		
STABLE ISOTOPES											
Delta-D (0/00)	-128.0(-129.5)LD	-130.5	ND	-127(-125)FD	ND	ND	ND	-138.0	ND	ND	ND
Delta O-18 (0/00)	-17.6	-17.5	ND	-16.7(-16.9)FD	ND	ND	ND	-18.4	ND	ND	ND
TRITIUM (tritium units)	0.10	-0.01	ND	12.6(18.6)FD	ND	ND	ND	0.06	ND	ND	ND

Table 5-1 Sierra Pacific Spring and Well Water Analyses

	22	23	24	25	26.0	27	28
	TW-15	Toano Well #1	Unnamed Well	Rocky Butte Well	Unnamed Well	Fivemile Draw Well	Unnamed Well 28
	39-66-9	40-65-24	40-65-10	41-67-22	41-64-25	41-66-33	41-65-35
Location Symbol on Figure 5-1	TW-15	24bd	10ca	22bc	25bb	33ac	35ad
FIELD PARAMETERS							
pH	7.7	7.5	8.55	8.25	ND	7.54	ND
Temperature (degrees C)	N.D	10	16.5	20.5	ND	12.5	ND
Specific Conductance(umhos/cm)	N.D.	280	330	320	ND	880	ND
Alkalinity as CaCO3(mg/L)	124	108	165	121	ND	227	132.0
MAJOR CATIONS (mg/L)							
Calcium	32	51	34	35	ND	128	44
Magnesium	10	8.8	6.7	7	ND	61	6.5
Sodium	15	22	54	25	ND	53	33
Potassium	6	5	9	13	ND	13	10
MAJOR ANIONS (mg/L)							
Chloride	7	24	9	12	ND	21	11
Sulfate	21	47	50	29	ND	344	44
Nitrite as N	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Nitrate as N	1.1	1.6	0.43	1.5	ND	3.4	0.52
Fluoride	0.3	0.3	0.6	0.4	ND	0.5	0.4
TRACE/MINOR INORGANICS (mg/L)							
Antimony	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	ND	<0.1	<0.1
Barium	0.12	0.061	0.055	0.071	ND	0.04	0.079
Boron	0.06	0.06	0.12	0.1	ND	0.14	0.10
Cadmium	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Copper	<0.006	<0.006	<0.007	<0.006	ND	<0.007	<0.006
Iron	<0.05	<0.05	0.13	<0.05	ND	<0.05	<0.05
Lead	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Lithium	<0.02	<0.02	0.04	0.02	ND	0.11	0.03
Manganese	<0.005	<0.005	0.009	0.005	ND	<0.005	<0.005
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	ND	<0.0002	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	ND	<0.2	<0.2
Silicon (Si)	28	27	38	33	ND	30	39
Silica (SiO2)	60	58	81	71	ND	64	83
Silver	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Zinc	0.12	<0.01	0.01	0.21	ND	0.11	<0.01
TOTAL DISSOLVED SOLIDS (mg/L)	203	310	330	260	ND	920	330
ION BALANCE (%)		4.2	2.4	4.7	-	6.1	-
STABLE ISOTOPES						6.1	
Delta-D (0/00)	-136.0	-132.0	-137.0	-128.0	-133.0	-122.0	-137.0
Delta O-18 (0/00)	-18.6	-17.2	-17.9	-16.3 (-16.4 LD)	-17.7	-15.7	-18.0
TRITIUM (tritium units)	0.15	0.60	-0.08	0.00	0.00	1.25	-0.07
	FD=Field Duplicate, LD=Lab Duplicate						
	( ) Values in parantheses are field or lab duplicate analyses						
	#Sample not chilled or preserved, holding times exceeded for TDS						
	ND=No Data						

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Table 6-1. CHILTON HYDROLOGIC MONITORING STATIONS, THOUSAND SPRINGS BASIN AND VICINITY

Precipitation Stations*	Period of Record
Wilkins	3/82 - 9/83, 2/86 - 10/88
Fivemile Ranch	3/82 - 9/83, 2/86 - 10/88
Lower Eccles	3/82 - 9/83, 2/86 - 10/88
Twelvemile Ranch	3/82 - 9/83, 2/86 - 10/88
HD Summit	2/83 - 9/83, 2/86 - 10/88
Moor Summit	2/83 - 9/83, 2/86 - 10/88
Pequop Summit	2/86 - 10/88
Cobre	3/86 - 10/88
Rocky Point	6/86 - 10/86
Pequop	3/83 - 9/83

Streamflow Stations*	Period of Record
WC Lane/Beaver Culvert	2/82 - 9/83, 2/86 - 10/88
Toano Draw	2/82 - 9/83, 2/86 - 10/88
Rock Springs Creek	2/82 - 9/83, 2/86 - 10/88
Eccles Narrows	2/82 - 9/83, 2/86 - 10/88
Twentyone Mile Junction	2/82 - 9/83, 2/86 - 10/88
Lower Schoolhouse	6/82 - 9/83, 2/86 - 10/88
Crittenden Creek	2/82 - 9/83, 2/86 - 10/88
Rocky Ford	2/82 - 9/83, 2/86 - 10/88
Wilkins/Wilkins Canal	2/82 - 9/83, 2/86 - 3/86
Narrows	2/82 - 9/83, 2/86 - 3/86
Highway 30	2/82 - 9/83, 2/86 - 4/86

Reservoir Stations*	Period of Record
Twentyone Mile Reservoir	2/82 - 9/83, 2/86 - 10/88
Dake Reservoir	2/82 - 9/83, 2/86 - 10/88

* Chilton Engineering (Kennedy/Jenks/Chilton), 1982-1988, Hydrologic Monitoring, Thousand Springs Creek for Woodward-Clyde Consultants - Hydrologic Monitoring Summary

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Table 6-2. PUBLISHED HYDROLOGIC MONITORING STATIONS, THOUSAND SPRINGS BASIN AND VICINITY

Agency	Precipitation Stations	Type of Data	Period of Record
NOAA[1]	Contact	Daily	1948 - 1987
	Metropolis	Daily	1964 - 1988
	Montello	Daily	1887 - 1988
	Pequop	Daily	1959 - 1985
	Wells	Daily	1891 - 1988
BLM[2]	Rock Spring Creek (23 stations)	Monthly	1963 - 1980

Agency	Streamflow Stations	Type of Data	Period of Record
USGS[3]	Thousand Springs Creek near Wilkins	Continuous	1985 - 1988
	Thousand Springs Creek near Shores	Continuous	1985 - 1986
	Thousand Springs Creek near Montello	Continuous	1985 - 1988

1 National Oceanic and Atmospheric Administration. 1940-1988. Climatological Data for Nevada.

2 Bureau of Land Management. September 1983. Nevada Watershed Studies, 1963-1980. Technical Publication BLMNVPT830014340.

3 United States Geological Survey. 1985-1988. Water Resources Data, Nevada, Water Year 1985, and Computer Generated Tables for Water Years 1986-1988.

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Table 6-3. ESTIMATED IRRIGATION WATER USE BY SUBBASINS, THOUSAND SPRINGS BASIN

Location and Type of Use	Area (ac)	Irrigation Water Use by Subbasin: Net Water Use (ac-ft/ac)	Net Water Use (ac-ft)	Application Efficiency (Percent)	Water Applied (ac-ft)	Water Source
I. Montello-Crittenden						
A. Native Pasture						
Rocky Ford No. 4	108	1.43	154	30	513	Thousand Springs Creek
Upper Gamble No. 3	254	1.43	363	30	1210	Thousand Springs Creek
Dake & Warm Springs	1000	1.91	1910	30	6367	Thousand Springs Creek[a]
	1362		2427		8090	
B. Improved Pasture						
Crittenden Nos. 6-8	107	1.53	164	50	328	Thousand Springs Creek
Gamble Ranch Nos. 1,2	743	1.53	1137	50	2274	Thousand Springs Creek
	850		1301		2602	
C. Alfalfa Haylands						
Gamble Farm Nos. 1-18	1448	2.21	3200	50	6400	Wells
Twelvemile No. 19	68	2.21	150	50	300	Spring
Twelvemile Nos. 21-23	434	2.21	959	50	1918	Wells
Twelvemile Nos. 24,25	63	2.21	139	50	278	Crittenden Reservoir
	2013		4448		8896	
Subtotal	4225		8176		19,588	
II. Rocky Butte						
A. Native Pasture						
Twentyone Mile Pasture	187	0.95	178	30	593	Thousand Springs Creek
Eighteen Mile No. 11	236	0.95	224	30	747	Thousand Springs Creek
Eighteen Mile No. 16	433	0.95	411	30	1370	Thousand Springs Creek
Eccles No. 10	856		813		2710	

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Table 6-3. ESTIMATED IRRIGATION WATER USE BY SUBBASINS, THOUSAND SPRINGS BASIN (concluded)

Location and Type of Use	Area (ac)	Irrigation Water Use by Subbasin: Net Water Use (ac-ft/ac)	Net Water Use (ac-ft)	Application Efficiency (Percent)	Water Applied (ac-ft)	Water Source
B. Improved Pasture						
Eighteen Mile Nos. 12-15	304	1.53	465	50	930	Thousand Springs Creek
Subtotal	1160		1278		3640	
III. Toano-Rock Spring[b]						
A. Native Pasture						
Ninemile Nos. 8,9	614	0.95	583	30	1943	Thousand Springs Creek
B. Improved Pasture						
Wine Cup Nos. 4-7	1086	2.04	2216	50	4432	Thousand Springs Creek
Subtotal	1700		2799		6375	
IV. Herrell Siding - Brush Creek						
A. Improved Pasture						
Brush Creek	349	2.04	712	50	1424	Brush Creek
Wine Cup Nos. 1-3	1105	2.04	2254	50	4508	Thousand Springs Creek
Subtotal	1454		2966		5932	
Subbasins I to IV, TOTAL	8539		15,219		35,535	

(a) Includes subirrigation by shallow groundwater.
(b) Native and improved pastures indicated below exist across Thousand Springs Creek floodplain, and would be in both Toano Creek and Rock Spring Creek Subbasins. Data provided or derived from Soil Conservation Service, 1988-1989. Subbasin classifications adopted from Rush 1968. Net water use (acre-feet) and water applied (acre-feet) derived by Woodward-Clyde Consultants.

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Table 6-4. AVERAGE MONTHLY AND ANNUAL PRECIPITATION AT NOAA MONITORING STATIONS, 1949 - 1983, THOUSAND SPRINGS BASIN AND VICINITY

Month	Precipitation at Monitoring Station* (inches)			
	Contact	Montello	Wells	Average
January	0.83	0.60	0.95	0.79
February	0.50	0.37	0.77	0.55
March	0.71	0.44	0.87	0.67
April	0.79	0.59	0.86	0.75
May	1.62	1.05	1.33	1.33
June	1.31	1.04	1.06	1.14
July	0.52	0.59	0.45	0.52
August	0.71	0.72	0.53	0.65
September	0.73	0.60	0.81	0.71
October	0.75	0.50	0.75	0.67
November	0.78	0.60	0.96	0.78
December	0.92	0.59	1.03	0.85
Annual	10.17	7.69	10.37	9.41

* Derived by Woodward-Clyde Consultants from National Oceanic and Atmospheric Administration. 1949-1983. Climatological Data for Nevada.

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Table 6-5. DRAINAGE AREAS FROM DRAINAGE BASIN MODEL, THOUSAND SPRINGS BASIN

Drainage Basin and Location	Drainage Area Within Each Subarea* (sq mi) Contact	Montello	Wells	Total
Thousand Springs Creek at Wilkins Gaging Station	9.23	0.00	58.64	67.87
Toano Draw at Confluence with Thousand Springs Creek**	0.00	188.89	62.72	251.61
Thousand Springs Creek at Shores Gaging Station	68.40	226.10	188.73	483.23
Thousand Springs Creek below Crittenden Creek	338.71	561.96	188.73	1089.40
Thousand Springs Creek at Montello Gaging Station	338.71	925.29	188.73	1452.73

* Each subarea corresponds to a Thiessen rainfall polygon.

** Drainage areas for Toano Draw were not used in the stream generation model, because the model was developed for Thousand Springs Creek and not for Toano Draw.

Numerical values derived by Woodward-Clyde Consultants using geographic information system and U.S. Geological Survey. 1981. Wells Nevada-Utah, 1:100000 topographic map and 1982. Jackpot, Nevada. Utah-Idaho, 1:100,000 topographic map.

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Table 6-6. RESULTS OF STREAMFLOW GENERATION MODEL, THOUSAND SPRINGS CREEK

Location	Drainage Area (sq mi)	Average Streamflow Coefficient* $\overline{K}$	Average Annual Precipitation (in.)	Average Annual Precipitation (ac-ft)	Average Annual Streamflow from Streamflow Generation Model (in.)	Average Annual Streamflow from Streamflow Generation Model (ac-ft)	Average Annual Streamflow from Streamflow Generation Model (cfs)
Thousand Springs Creek at Wilkins Gaging Station	67.87	0.246	14.01	50,718	3.45	12,477	17.23
Thousand Springs Creek at Shores Gaging Station	483.23	0.0270	12.67	326,584	0.34	8,818	12.18
Thousand Springs Creek below Crittenden Creek	1089.40	0.0070	12.63	734,042	0.088	5,138	7.10
Thousand Springs Creek at Montello Gaging Station	1452.73	0.0042	12.20	945,307	0.051	3,979	5.50

* $\overline{K}$ is the ratio of average annual streamflow (ac-ft) to average annual precipitation (ac-ft).

Streamflow values derived by Woodward-Clyde Consultants.

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Table 6-7. STREAMFLOW GENERATION MODEL, RUSH (1968) SUBBASINS, THOUSAND SPRINGS BASIN

Name of Subbasin*	Drainage Area Individual (sq. mi.)	Drainage Area Cumulative (sq. mi.)	Average Coeff. $\bar{K}$	Average Annual Precipitation Cumul. (ac ft)	Average Annual Precipitation Indiv. (ac ft)	Average Annual Precipitation Indiv. (in.)	Average Annual Streamflow** Cumul (ac ft)	Average Annual Streamflow** Indiv. (ac ft)	Average Annual Streamflow** Indiv. (cfs)	Average Annual Streamflow** Indiv. (in.)
Herrell Siding	159.38	159.38	0.1110	109,912	109,912	12.93	12,200	12,200	16.85	1.44
Toano Draw	328.16	487.54	0.0261	328,072	218,160	12.47	8,563	-3,637	-5.02	-0.21
Rock Spring	281.71	769.25	0.0125	523,012	194,940	12.98	6,538	-2,025	-2.80	-0.13
Rocky Butte	186.34	955.59	0.0087	642,217	119,205	12.00	5,587	-951	-1.31	-0.10
Montello Crittenden	490.64	1446.23***	0.0042	945,307	303,090	11.58	3,979	-1,608	-2.22	-0.06

*Subbasins are from Rush (1968).

**Negative average annual streamflow values mean flow lost to groundwater or withdrawn for irrigation.

***Compares closely with 1,452.73 square miles for the same location, Thousand Springs Creek at Montello Gaging Station (Table 6-5).

Numerical values derived by Woodward-Clyde Consultants.

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Table 6-8. RESULTS OF HYDROLOGIC BUDGET ANALYSIS, THOUSAND SPRINGS BASIN AND TOANO DRAW SUBBASIN

Drainage Area/ Average Annual Parameter of Hydrologic Budget	Thousand Springs Creek At Montello Gaging Station		Toano Draw At Confluence With Thousand Springs Creek[b]
	Existing Conditions	Modified Conditions[a]	
Drainage Area (sq mi)	1452.73	1452.73	251.61
Precipitation (P)	945,307	945,307	163,725
Evapotranspiration (ET)*	850,776	850,776	147,353
Streamflow	3,979	15,039	2,605
Net Irrigation (NI)	15,219	0	0
Groundwater Applied (GA)	8,318	0	0
Irrigation Return (IR)	20,316	0	0
Groundwater Recharge (GR)	63,335	79,492	13,768
Maxey-Eakin **	61,236	61,236	11,558
Groundwater Outflow (GO)	75,333	79,492	13,768
Darcian Flow Calculation Estimate	56,700	--	6,100

Numerical values estimated by Woodward-Clyde Consultants based on water budget analysis.

All hydrologic budget parameters indicated in acre-feet/year except drainage area in square miles.

* Assumes ET is 90% of precipitation.
** Estimate based on applying Maxey-Eakin method (Watson et al. 1975).

[a] Modified to account for net consumption of water by irrigated agriculture (NI, IR, and GA equal to zero). These are not actual conditions but are presented as an intermediate step to derive the Toano Draw water budget.

[b] With the exception of drainge area and Maxey-Eakin values, Toano Draw parameters are scaled from Montello modified conditions, based on ratio of drainage areas.

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Table 7-1. ESTIMATED AREAS AND PRECIPITATION ABOVE VARIOUS ELEVATIONS - THOUSAND SPRINGS BASIN AND TOANO DRAW AND WILKINS SUBBASINS

Contour Interval (meters)	Area within Interval (square miles)			Cumulative Area						Total Average Annual Precipitation Within Interval (acre-feet)			Cumulative Total Average Annual Precipitation (acre-feet)		
				Thousand Srings Basin		Toano Draw Subbasin		Wilkins Gaging Sta. Subbasin							
	Thousand Springs Basin	Toano Draw Subbasin	Wilkins Gaging Sta. Subbasin	Area sq. mi.	Percent of total	Area sq. mi.	Percent of total	Area sq. mi.	Percent of total	Thousand Springs Basin	Toano Draw Subbasin.	Wilkins Gaging Sta. Subbasin	Thousand Springs Basin	Toano Subbasin	Wilkins Gaging Sta.
2600-2720	0.11	-	-	0.11	.01	-	--	-	--	144	-	-	144	-	-
2480-2600	0.62	-	0.51	0.73	.05	-	--	0.51	0.7	1352	-	595	1496	-	595
2360-2480	25.35	1.03	1.27	26.08	1.8	1.03	0.4	1.78	2.6	5672	1078	1367	7168	1078	1962
2240-2360	77.38	4.40	1.73	103.46	7.1	5.43	2.2	3.51	5.2	17,416	4211	1706	24,584	5289	3668
2120-2240	105.41	9.83	7.41	208.87	14.4	15.26	6.1	10.95	16.1	55,287	8573	6643	79,871	13,862	10,311
2000-2120	118.05	19.68	10.68	326.92	22.5	34.94	13.9	21.63	31.9	98,901	15,487	8663	178,772	29,349	18,974
1880-2000	194.38	52.73	25.32	521.30	35.9	87.67	34.8	46.95	69.1	179,064	36,918	18,135	357,836	66,267	37,109
1760-1880	359.16	103.78	20.72	880.46	60.6	191.45	76.1	67.67	99.7	277,023	65,289	13,473	634,859	131,556	50,582
1640-1760	333.13	60.14	0.23	1213.59	83.5	251.59	99.9	67.90	100	202,682	34,242	136	837,541	165,798	50,718
1520-1640	159.35	.02	-	1372.94	94.6	251.61	100	67.90	100	76,664	10	-	914,205	165,808	50,718
1400-1520	79.78	-	-	1452.72	100	251.61	100	67.90	100	31,102	-	-	945,307	165,808	50,718

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Table 7-2. SOURCES OF POWER PLANT WATER BY GENERATING UNIT AND WATER DEVELOPMENT OPTION

Generating Unit	Development Option		
	Case 1	Case 2	Case 3
1 & 2	Toano Draw South	Toano Draw South	Toano Draw South
3 & 4	Toano Draw Middle	Montello Area	Montello Area
5	Toano Draw North	Montello Area	Toano Draw Middle
6	Twentyone Mile Dam to Crittenden Creek	Montello Area	Toano Draw Middle (Case 3A) or North (Case 3B)
7	Twentyone Mile Dam to Crittenden Creek	Montello Area	Montello Area
8	Montello Area	Toano Draw Middle (Case 2A) or South (Case 2B)	Montello Area

NOTE: Cases are as evaluated by numerical modeling and discussed in Section 8.0

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Table 8-1. ESTIMATE OF RECHARGE BASED ON THE MAXEY-EAKIN METHOD

Precipitation Range (in)	Recharge (% of Precipitation)	Equivalent Elevation Range (ft, msl)	Mean Precipitation (in)	Equivalent Recharge Rate (in)	Mean Recharge (in)
>20	25	>7678	20	>5	5
15-20	15	6503-7678	17.5	2.25-3.0	2.625
12-15	7	5799-6503	13.5	0.84-1.05	0.945
8-12	3	4859-5799	10	0.24-0.36	0.30
<8	0	<4859	0	0	0

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Table 8-2. MEASURED AND SIMULATED HYDRAULIC HEADS AT THE OBSERVATION NODES

Serial Number	Well ID	Measured Head (ft, msl)	Simulated Head (ft, msl)	Difference* (ft)
1	42-66-35b	5230.0	5229.1	0.9
2	42-66-8ad	5290.0	5261.0	29.0
3	MW-1	5385.0	5372.7	12.3
4	MW-4	5457.0	5441.2	15.8
5	41-66-24cb	5873.0	5868.7	4.3
6	41-67-22bc	5152.0	5253.8	-101.8
7	41-65-35b	5465.0	5455.5	9.5
8	41-65-35a	5465.0	5456.7	8.3
9	41-66-35a	5526.0	5522.8	3.2
10	TW-12	5471.0	5484.2	-13.2
11	40-65-2ab	5470.0	5463.7	-6.3
12	40-67-11bb	5449.0	5439.9	-9.1
13	40-66-8cd	5567.0	5589.3	-22.3
14	40-67-21bb	5557.0	5576.2	-19.2
15	40-65-24bd	5498.0	5501.7	-3.7
16	MW-2	5484.0	5505.5	-21.5
17	40-67-28ad	6023.0	6018.9	4.1
18	40-65-27d	5502.0	5512.0	-10.0
19	40-66-25d	5822.0	5815.0	7.0
20	40-67-32b	6068.0	6036.6	31.4
21	40-65-27d	6002.0	6018.0	-16.0
22	40-66-25d	5523.0	5514.5	8.5
23	MW-3	5515.0	5516.2	-1.2
24	39-65-3ad	5710.0	5709.1	-0.9
25	TW-15	5511.0	5525.2	-14.2
26	39-67-18ad	6085.0	6062.0	23.0
27	TW-14	5517.0	5528.8	-11.8
28	39-66-16dc	5607.0	5577.1	29.9
29	39-67-21a	6402.0	6397.1	4.9
30	39-65-30b	6128.0	6138.8	-10.8
31	Spring	6060.0	6058.6	1.4

* Measured head - Simulated head

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Table 8-3. CALIBRATED STEADY-STATE WATER BALANCE OF THE MODEL AREA

Flux	Acre-Feet/Year
Inflow	
Recharge	8340
Leakage from the creek to the aquifer	1669
Total Inflow	10,009
Outflow	
Constant Head	1208
Evapotranspiration	4612
Flow from aquifer to the creek	4192
Total Outflow	10,012

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Table 8-4. SIMULATED WATER BALANCE FOR FIVE CASES OF GROUNDWATER DEVELOPMENT

Case	Demand (ac-ft/yr)	Elapsed Time (years)	ET (ac-ft/yr)	Recharge from River (ac-ft/yr)	Discharge to River (ac-ft/yr)	Net Discharge to River (ac-ft/yr)	Groundwater Outflow (ac-ft/yr)
0	0	0	4612	1669	4192	2523	1208
1	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	4	4597	1669	4072	2403	1207
	12,000	6	4573	1669	4000	2331	1207
	16,000	8	4515	1669	3819	2150	1207
	20,000	10	3994	1784	2822	1038	1207
	24,000	12	3549	1887	1842	-45	1193
	28,000	20	1358	2485	340	-2145	1055
	28,000	35	681	2766	16	-2750	849
	24,000	36	657	2773	15	-2758	833
	24,000	37	648	2780	14	-2766	814
	20,000	39	629	2792	12	-2780	775
	16,000	41	613	2804	10	-2794	735
	17,000	43	602	2815	8	-2807	695
	8000	45	592	2824	7	-2817	656
	4000	47	587	2825	5	-2820	634
2A	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	10	4585	1669	4037	2368	1207
	8000	14	4575	1669	4006	2337	1207
	12,000	20	4456	1669	3637	1968	1207
	12,000	35	4146	1780	2851	1071	1206
	8000	36	4121	1788	2820	1032	1205
	8000	37	4097	1797	2790	993	1205
	4000	45	3902	1839	2589	750	1204
	4000	49	3807	1850	2514	664	1203

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Table 8-4. SIMULATED WATER BALANCE FOR FIVE CASES OF GROUNDWATER DEVELOPMENT (concluded)

Case	Demand (ac-ft/yr)	Elapsed Time (years)	ET (ac-ft/yr)	Recharge from River (ac-ft/yr)	Discharge to River (ac-ft/yr)	Net Discharge to River (ac-ft/yr)	Groundwater Outflow (ac-ft/yr)
2B	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	10	4585	1669	4037	2368	1207
	8000	14	4575	1669	4006	2337	1207
	12,000	20	4550	1669	3931	2262	1207
	12,000	35	4427	1682	3603	1921	1205
	8000	36	4417	1686	3579	1893	1205
	4000	37	4407	1690	3555	1865	1205
	4000	45	4252	1757	2991	1234	1204
	4000	49	4117	1786	2765	979	1203
3A	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	8	4589	1669	4047	2378	1207
	12,000	10	4566	1669	3981	2312	1207
	16,000	20	4215	1751	2902	1151	1207
	16,000	35	3172	1953	2472	519	1206
	12,000	36	3127	1961	2464	503	1205
	12,000	37	3104	1966	2456	490	1205
	8000	43	3029	1980	2399	419	1204
	4000	45	3010	1985	2377	392	1204
3B	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	8	4589	1669	4047	2378	1207
	12,000	10	4566	1669	3981	2312	1207
	16,000	20	3546	1978	2431	453	1207
	16,000	35	2886	2068	2273	205	1206
	12,000	36	2879	2069	2262	193	1205
	12,000	37	2872	2072	2254	182	1205
	8000	43	2823	2098	2228	130	1204
	4000	45	2804	2100	2219	119	1204

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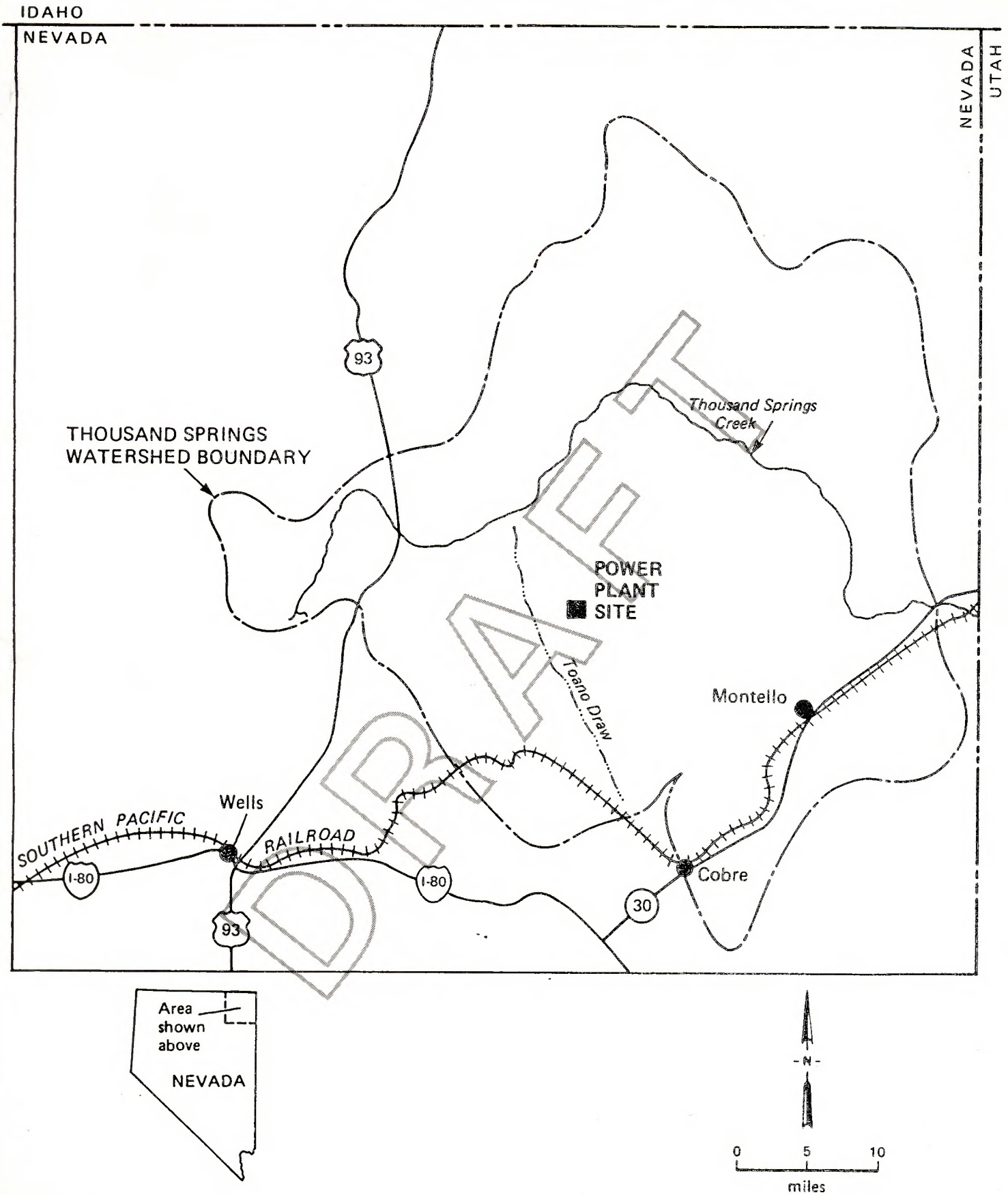


Project No. 90270B	Thousand Springs Power Plant	FACILITY AREA MAP	Figure 2-1
Woodward-Clyde Consultants			

T43N

T42N

T41N

T40N

T39N

THOUSAND SPRINGS BASIN BOUNDARY

PROPOSED THOUSAND SPRINGS POWER PLANT

A

A'

B

B'

C

C'

D

Profile IA

Profile I

Profile II

Profile III

Profile IV

Profile V

Profile VI

Profile VII

Profile X

Profile IX

Profile XII

LEGEND

• • • • • • Dipole-dipole resistivity survey

+ 45 TDEM sounding station

Profile V TDEM sounding profile

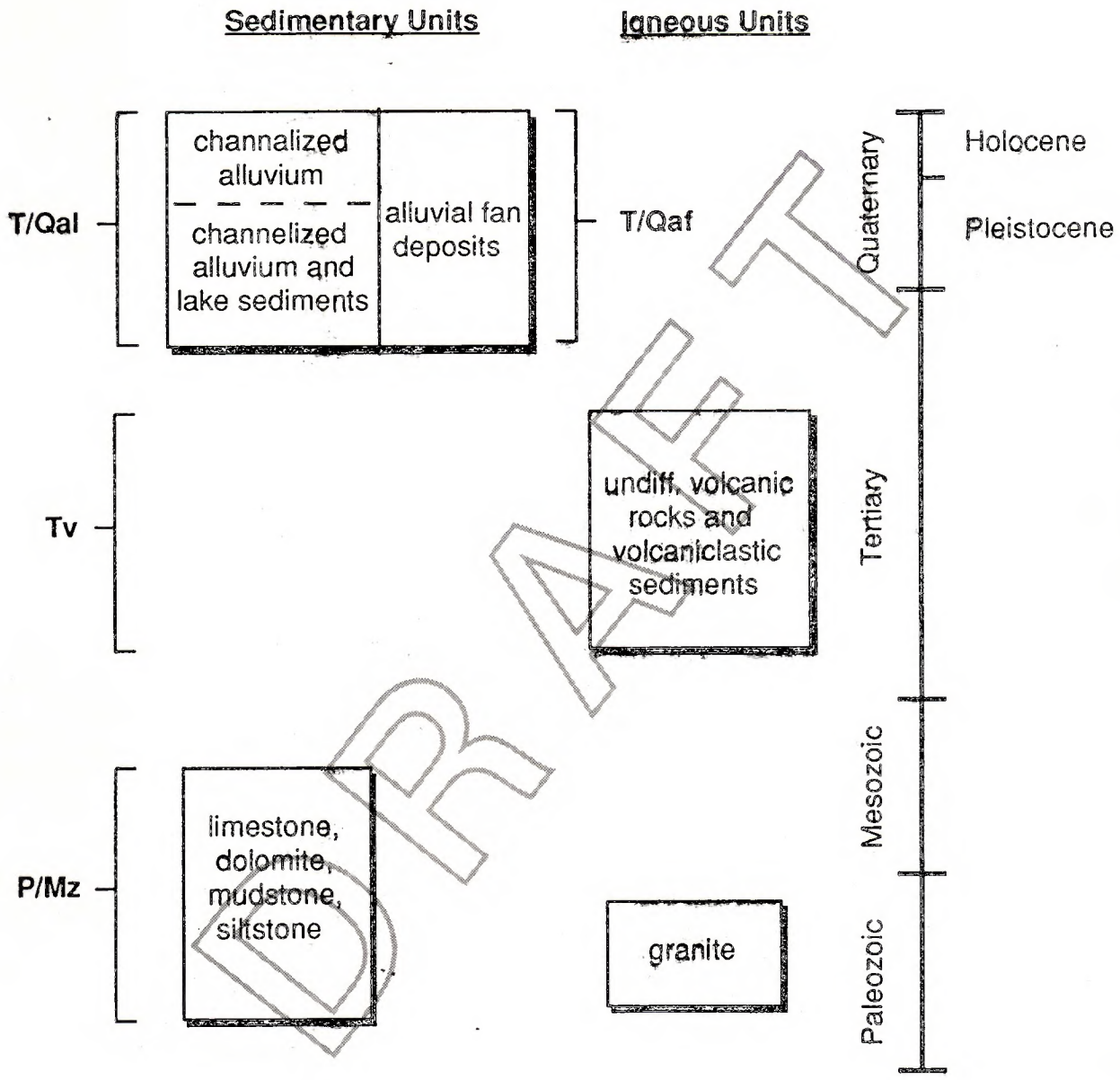
A —— A' Geologic cross-section

N

LOCATION OF TDEM SOUNDINGS DIPOLE-DIPOLE RESISTIVITY SURVEYS, GEOPHYSICAL PROFILES, AND GEOLOGIC CROSS-SECTIONS

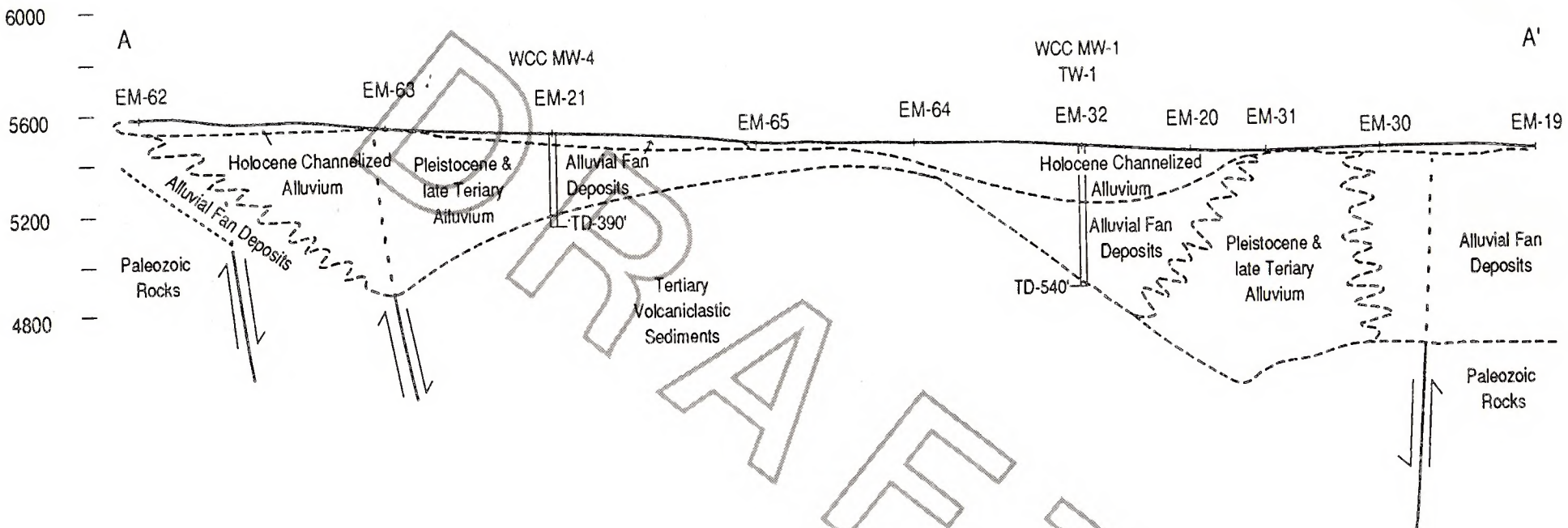
Project No. 90270B	Thousand Springs Power Plant	Figure 3-2
Woodward-Clyde Consultants		

Stratigraphy



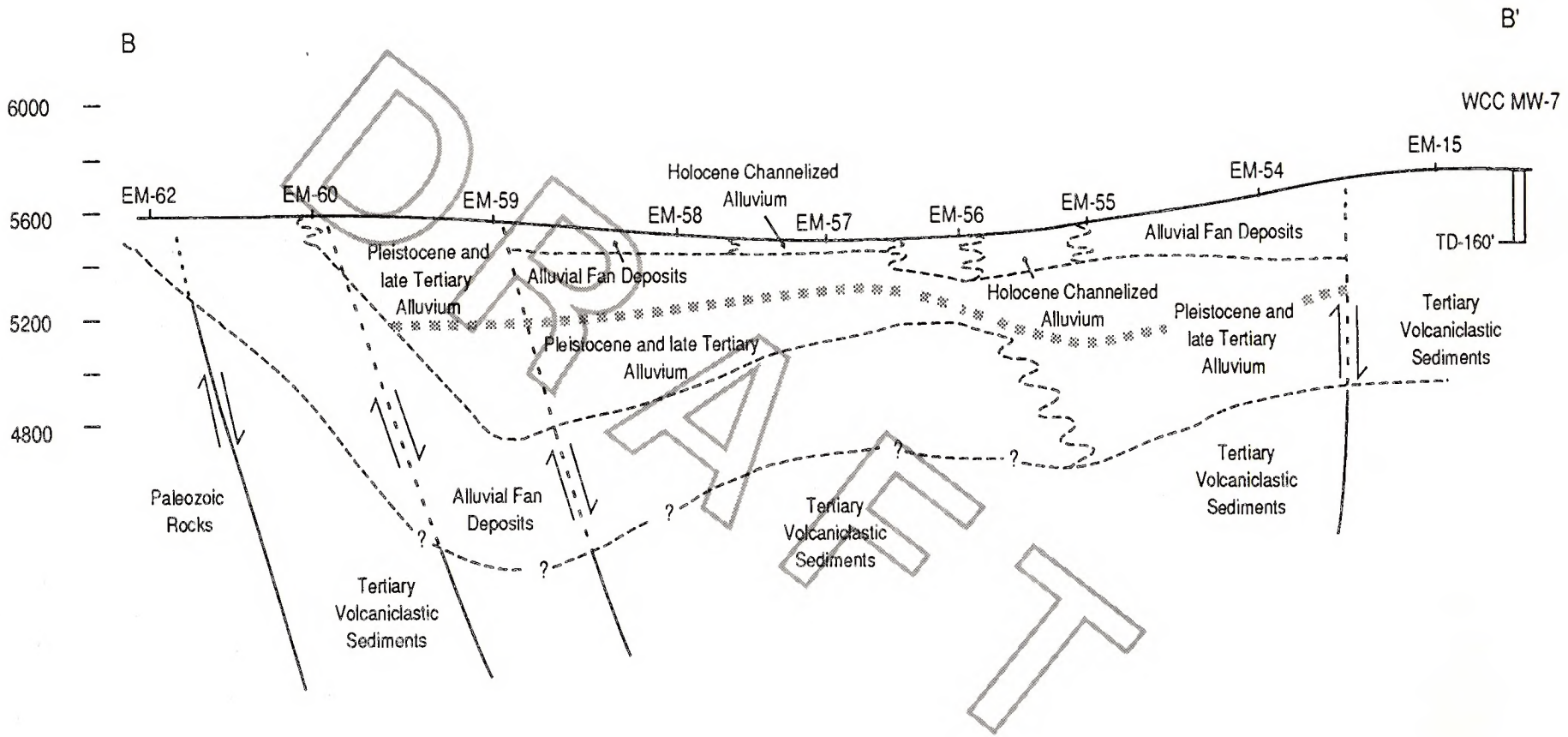
DRAFT

Project No. 90270B	Thousand Springs Power Plant	STRATIGRAPHIC CORRELATION CHART	Figure 3-3
Woodward-Clyde Consultants			



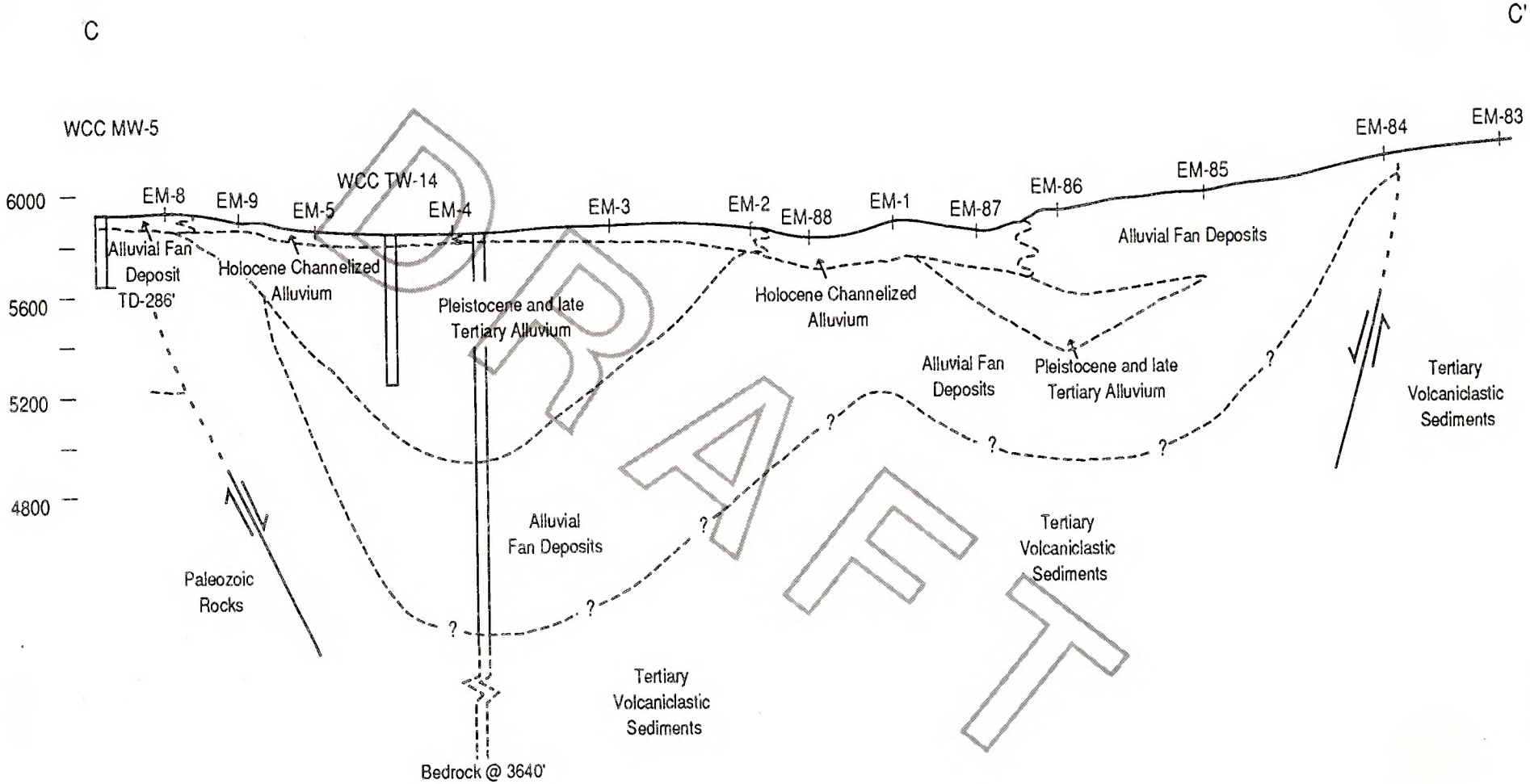
DRAFT

Project No. 90270B	Thousand Springs Power Plant	CROSS-SECTION A-A'	Figure 3-4
Woodward-Clyde Consultants			



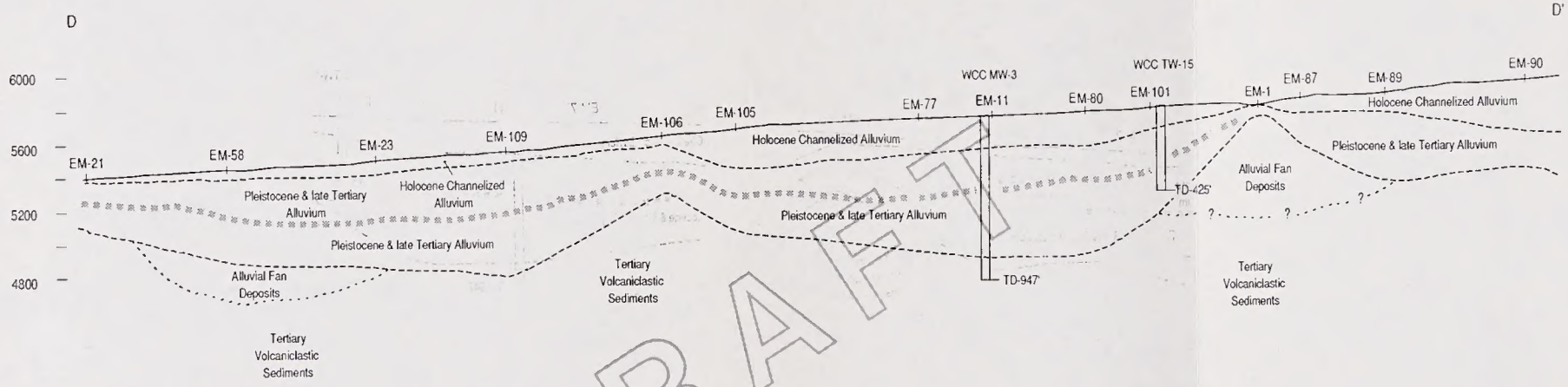
DRAFT

Project No. 90270B	Thousand Springs Power Plant	CROSS-SECTION B-B'	Figure 3-5
Woodward-Clyde Consultants			



DRAFT

Project No. 902708	Thousand Springs Power Plant	CROSS-SECTION C-C'	Figure 3-6
Woodward-Clyde Consultants			



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Project No. 90270B	Thousand Springs Power Plant	GEOLOGIC CROSS-SECTION D-D'	Figure 3-7
Woodward-Clyde Consultants			

T43N
T42N
T41N
T40N
T39N
T38N

THOUSAND SPRINGS BASIN BOUNDARY

PROPOSED THOUSAND SPRINGS POWER PLANT

4ab
11ac
12da
16dd
20ad
26ac
28ad
25da
35bd
35aa
32bc
5a
2ab
8ad1
9aa
8ad4
8ad2
8ad3
10bd
20da
MW-6
27aa
27dd
25aa (u)
29ba (u)
32ba
MW-1
TW-1
35ac
35ad
3(u)
1cb
11bb
10c
8dd
10ac
6cd
9
7dd
14ca (u)
20aa
20b(u)
MW-4
MW-7 (u)
23cb
24cb
22bc
21cc (u)
29db
30ad
36ab
28bb (u)
27bb
25bb
25ca
25a(u)
25cac1
25cac2
25db1
25db2
35bc(u)
34da(u)
35bd(u)
35ad(u)
MW-17
MW-12
TW-12
33a
2ab1
2ab2
2ab3
3aa
3ab
1ac
5ad
4b
TW-16
2cd
1d
12ab
12aa
12ac
12cc
10ca1
10ca2
8cd1
8cd2
15ac
16cac
16cbd
16cad
16ccb
21ab
14bb
14cb(u)
14cd
13dcd
15dd (u)
19aa
16cc
23ad1
23ad2
22bc
23db
16c(u)
24
24dd
24bd1 (u)
24bd2
MW-2
23d
27b(u)
27a(u)
27c(u)
27d(u)
26d
35b(u)
35aa(u)
35d(u)
34cd
35c(u)
3aa
*1
MW-3
TW-3
1aa
31bb
35ab
35cc
*2
10ab
25bb(u)
25ac
28ac
27ba(u)
34baa
34bda
25
36dc(u)
5ab
3ad
1cd
10bb
3dc
TW-15
16bb
18ad
9ca
17a
14cd
13dd
16dc1(u)
16dc2(u)
TW-14
21aa
21ac
15dd
22bb (u)
21dd
19aa
22bb
19bd
20cd
25ad
25db
29b
30b
MW-5 (u)
30bb
30c
33ac
33cb
33cc
31ac
31ad
34dd
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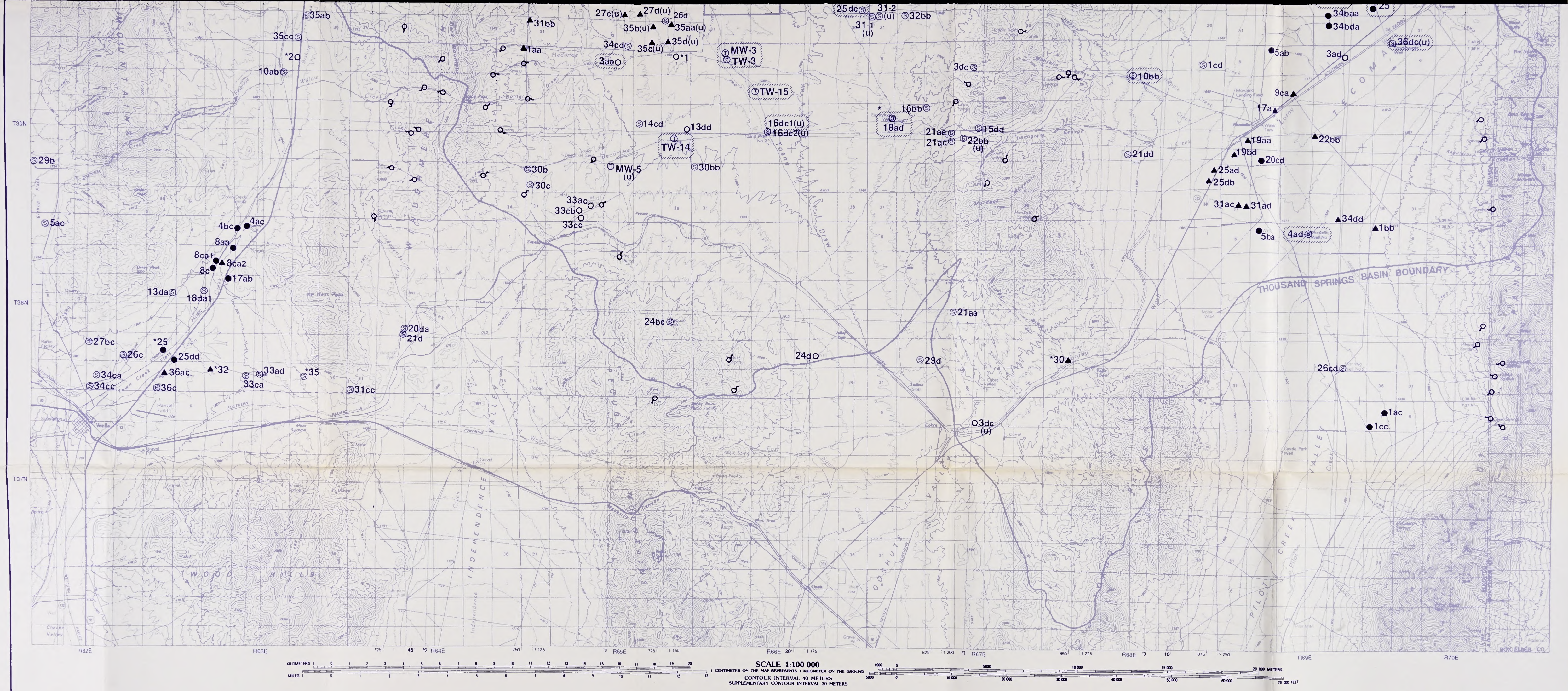

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LEGEND

Ⓣ Test wells and monitoring wells installed by Woodward-Clyde Consultants, 1988

Ⓢ Stock well

● Irrigation well

▲ Domestic well

○ Other well (Industrial, Construction, etc.)

(u) Well unused or abandoned

Spring – Identified from USGS 1:100,000 scale topographic map, Bureau of Land Management Computer data base, or from WCC field reconnaissance

* Well location plotted in center of section, drillers log does not provide precise location within section

Ⓣ TW-15 Wells and springs proposed for monitoring

WELL IDENTIFICATION KEY

b	b / a / c / d
c	d

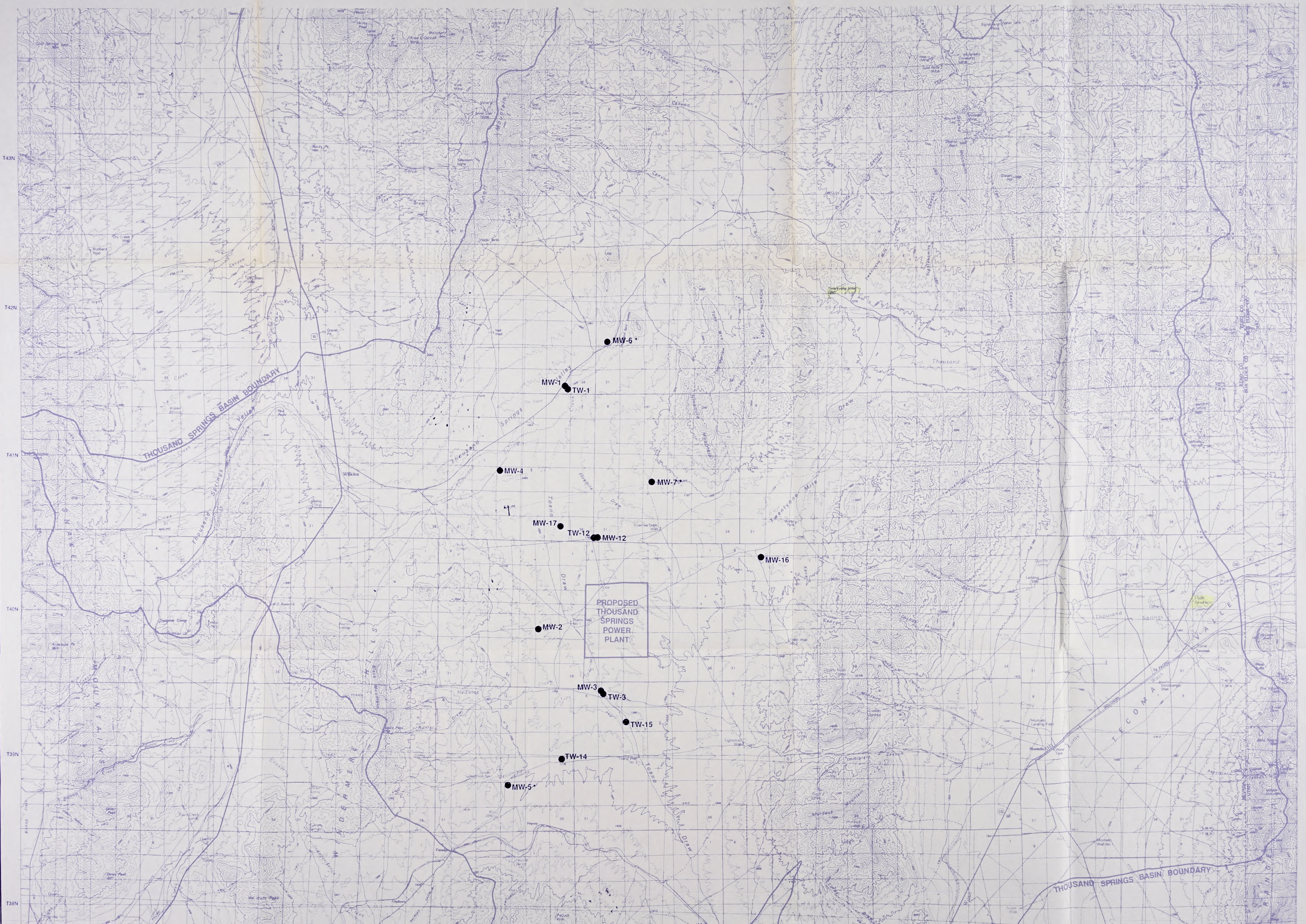
35

35 ad = SE 1/4, NE 1/4 Sec 35

WELL AND SPRING LOCATION MAP AND WELLS AND SPRINGS PROPOSED FOR HYDROLOGICAL MONITORING PROGRAM

Project No. 90270B	Thousand Springs Power Plant	Figure 4-1

Woodward-Clyde Consultants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T40N
T39N
T38N
MW-6
MW-1
TW-1
MW-4
MW-7
MW-17
TW-12
MW-12
MW-16
PROPOSED THOUSAND SPRINGS POWER PLANT
MW-2
MW-3
TW-3
TW-15
TW-14
MW-5
THOUSAND SPRINGS BASIN BOUNDARY
THOUSAND SPRINGS BASIN BOUNDARY

LEGEND

- ● Test well (TW – ___) or monitoring well (MW – ___) installed by Woodward-Clyde Consultants, 1988

* Note: No well was installed in these borings.

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LOCATIONS OF MONITORING WELLS AND TEST WELLS

Project No. 90270B	Thousand Springs Power Plant	Figure 4-2
Woodward-Clyde Consultants		

PROPOSED GEOTHERMAL POWER PLANT
MW-1
MW-3
MW-4
MW-5
MW-16
TW-14
TW-15
THOUSAND SPRINGS BASIN BOUNDARY
T.16N.
T.15N.
T.14N.
T.13N.
R.17E.
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R.780E.
R.781E.
R.782E.
R.783E.
R.784E.
R.785E.
R.786E.
R.787E.
R.788E.
R.789E.
R.790E.
R.791E.
R.792E.
R.793E.
R.794E.
R.795E.
R.796E.
R.797E.
R.798E.
R.799E.
R.800E.
R.801E.
R.802E.
R.803E.
R.804E.
R.805E.
R.806E.
R.807E.
R.808E.
R.809E.
R.810E.
R.811E.
R.812E.
R.813E.
R.814E.
R.815E.
R.816E.
R.817E.
R.818E.
R.819E.
R.820E.
R.821E.
R.822E.
R.823E.
R.824E.
R.825E.
R.826E.
R.827E.
R.828E.
R.829E.
R.830E.
R.831E.
R.832E.
R.833E.
R.834E.
R.835E.
R.836E.
R.837E.
R.838E.
R.839E.
R.840E.
R.841E.
R.842E.
R.843E.
R.844E.
R.845E.
R.846E.
R.847E.
R.848E.
R.849E.
R.850E.
R.851E.
R.852E.
R.853E.
R.854E.
R.855E.
R.856E.
R.857E.
R.858E.
R.859E.
R.860E.
R.861E.
R.862E.
R.863E.
R.864E.
R.865E.
R.866E.
R.867E.
R.868E.
R.869E.
R.870E.
R.871E.
R.872E.
R.873E.
R.874E.
R.875E.
R.876E.
R.877E.
R.878E.
R.879E.
R.880E.
R.881E.
R.882E.
R.883E.
R.884E.
R.885E.
R.886E.
R.887E.
R.888E.
R.889E.
R.890E.
R.891E.
R.892E.
R.893E.
R.894E.
R.895E.
R.896E.
R.897E.
R.898E.
R.899E.
R.900E.
R.901E.
R.902E.
R.903E.
R.904E.
R.905E.
R.906E.
R.907E.
R.908E.
R.909E.
R.910E.
R.911E.
R.912E.
R.913E.
R.914E.
R.915E.
R.916E.
R.917E.
R.918E.
R.919E.
R.920E.
R.921E.
R.922E.
R.923E.
R.924E.
R.925E.
R.926E.
R.927E.
R.928E.
R.929E.
R.930E.
R.931E.
R.932E.
R.933E.
R.934E.
R.935E.
R.936E.
R.937E.
R.938E.
R.939E.
R.940E.
R.941E.
R.942E.
R.943E.
R.944E.
R.945E.
R.946E.
R.947E.
R.948E.
R.949E.
R.950E.
R.951E.
R.952E.
R.953E.
R.954E.
R.955E.
R.956E.
R.957E.
R.958E.
R.959E.
R.960E.
R.961E.
R.962E.
R.963E.
R.964E.
R.965E.
R.966E.
R.967E.
R.968E.
R.969E.
R.970E.
R.971E.
R.972E.
R.973E.
R.974E.
R.975E.
R.976E.
R.977E.
R.978E.
R.979E.
R.980E.
R.981E.
R.982E.
R.983E.
R.984E.
R.985E.
R.986E.
R.987E.
R.988E.
R.989E.
R.990E.
R.991E.
R.992E.
R.993E.
R.994E.
R.995E.
R.996E.
R.997E.
R.998E.
R.999E.
R.1000E.

SCALE 1:100 000

1 CENTIMETER ON THE MAP REPRESENTS 1 KILOMETER ON THE GROUND

CONTOUR INTERVAL 40 METERS

SUPPLEMENTARY CONTOUR INTERVAL 20 METERS

LEGEND

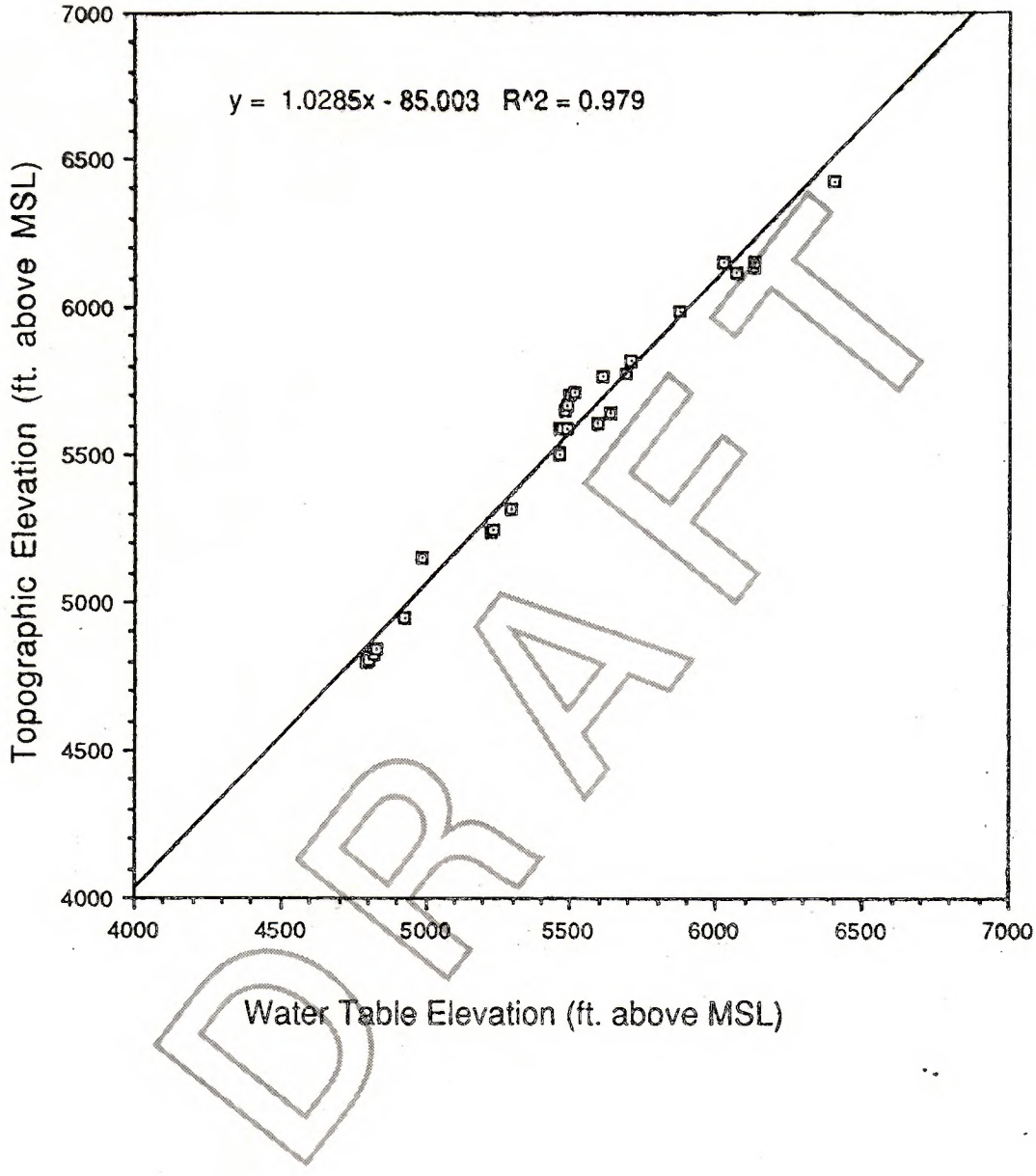
- Contours of approximate thickness of the unconsolidated aquifer, in feet
- 50 foot isopach contour
- Fault, dashed where approximate, dotted where concealed, and indicated by gravity data; ball on down-dropped side
- MW-1 — Location of well having geological log
- Δ 650' / 48 — Time domain electromagnetic data station, value posted is approximate thickness of unconsolidated aquifer in feet

Note: Thickness of unconsolidated aquifer posted at MW and TW series well locations determined from well logs

-N-

ISOPACH MAP OF THE ALLUVIAL AQUIFER

Project No. 90270B	Thousand Springs Power Plant	Figure 4-3
Woodward-Clyde Consultants		



DRAFT

Project No. 90270B	Thousand Springs Power Plant	RELATIONSHIP OF WATER TABLE TO TOPOGRAPHIC ELEVATION	Figure 4-4
Woodward-Clyde Consultants			

T43N

T42N

T41N

T40N

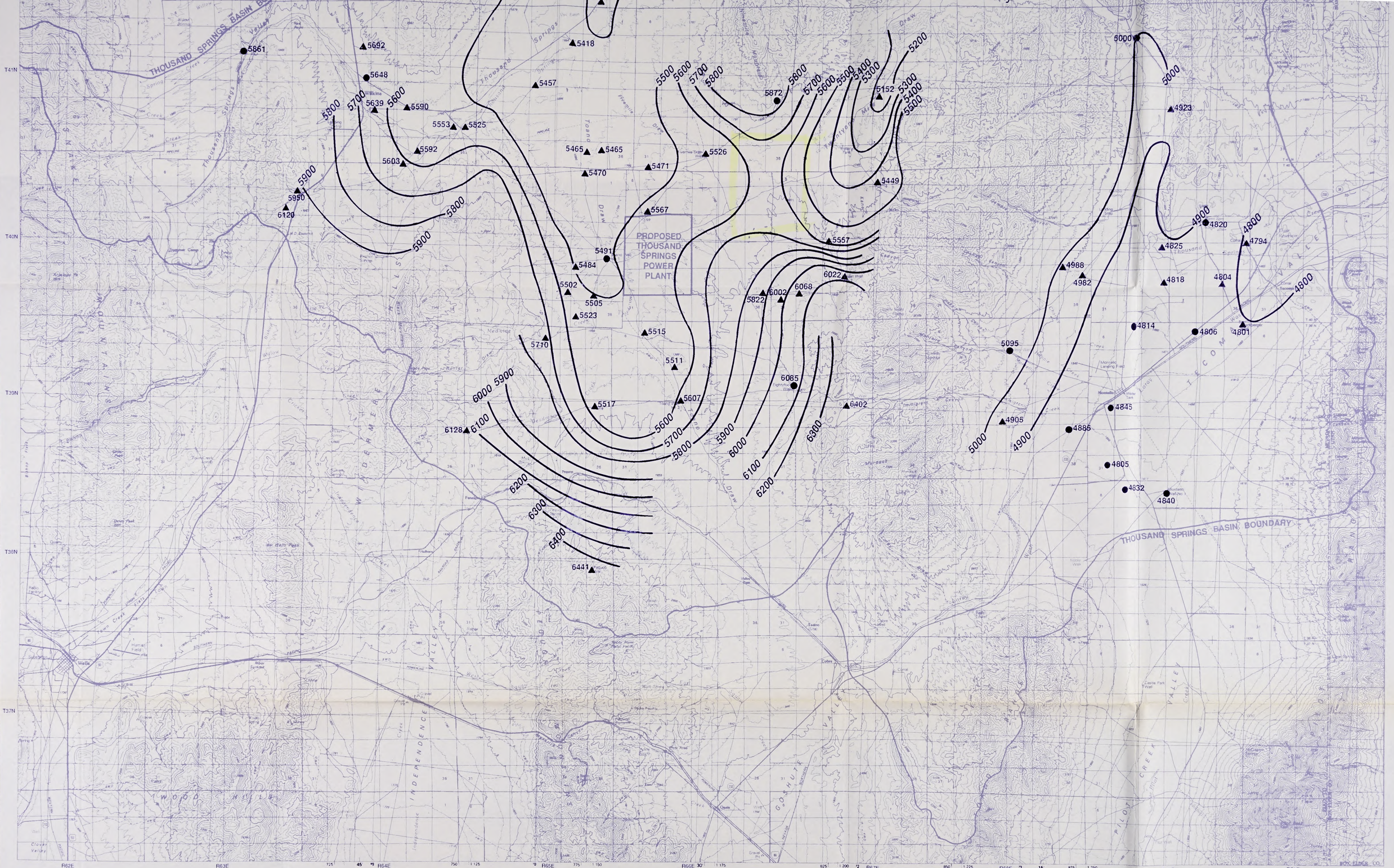
T39N

T38N

THOUSAND SPRINGS BASIN BOUNDARY

PROPOSED THOUSAND SPRINGS POWER PLANT

THOUSAND SPRINGS BASIN BOUNDARY



SCALE 1:100 000

1 CENTIMETER ON THE MAP REPRESENTS 1 KILOMETER ON THE GROUND

CONTOUR INTERVAL 40 METERS

SUPPLEMENTARY CONTOUR INTERVAL 20 METERS

LEGEND

▲ Water level measured by WCC, 1988

● Water level measured by Guytron (1982), USGS (1988, unpublished data) or obtained from original drillers log.

-N-

WATER TABLE CONTOUR MAP

Project No. 90270B	Thousand Springs Power Plant	Figure 4-5
Woodward-Clyde Consultants		

Project No. 90270B

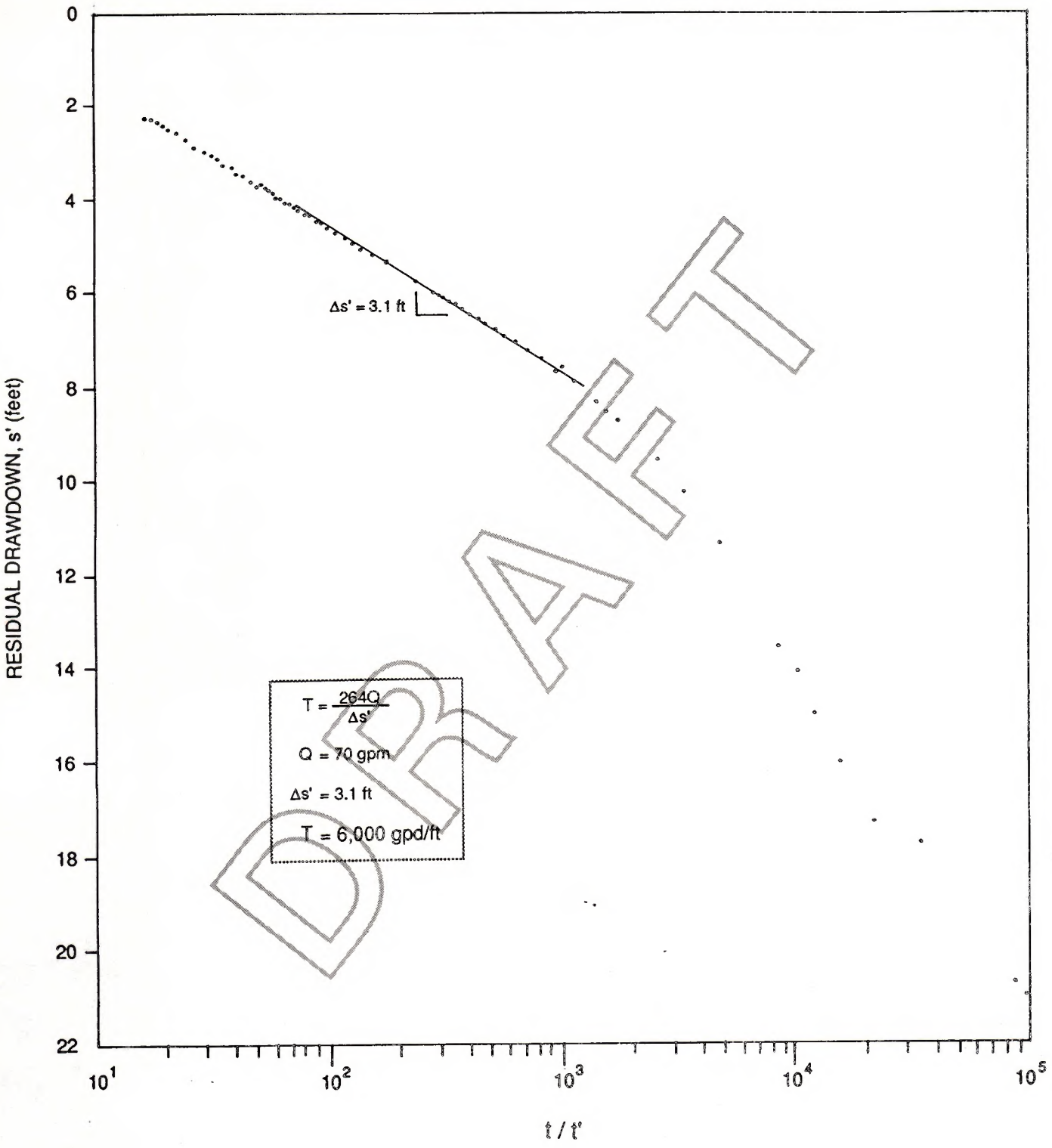
Thousand Springs Power Plant

Woodward-Clyde Consultants

DRAWDOWN PLOT FOR TW-1 AND MW-1
COOPER-JACOB METHOD

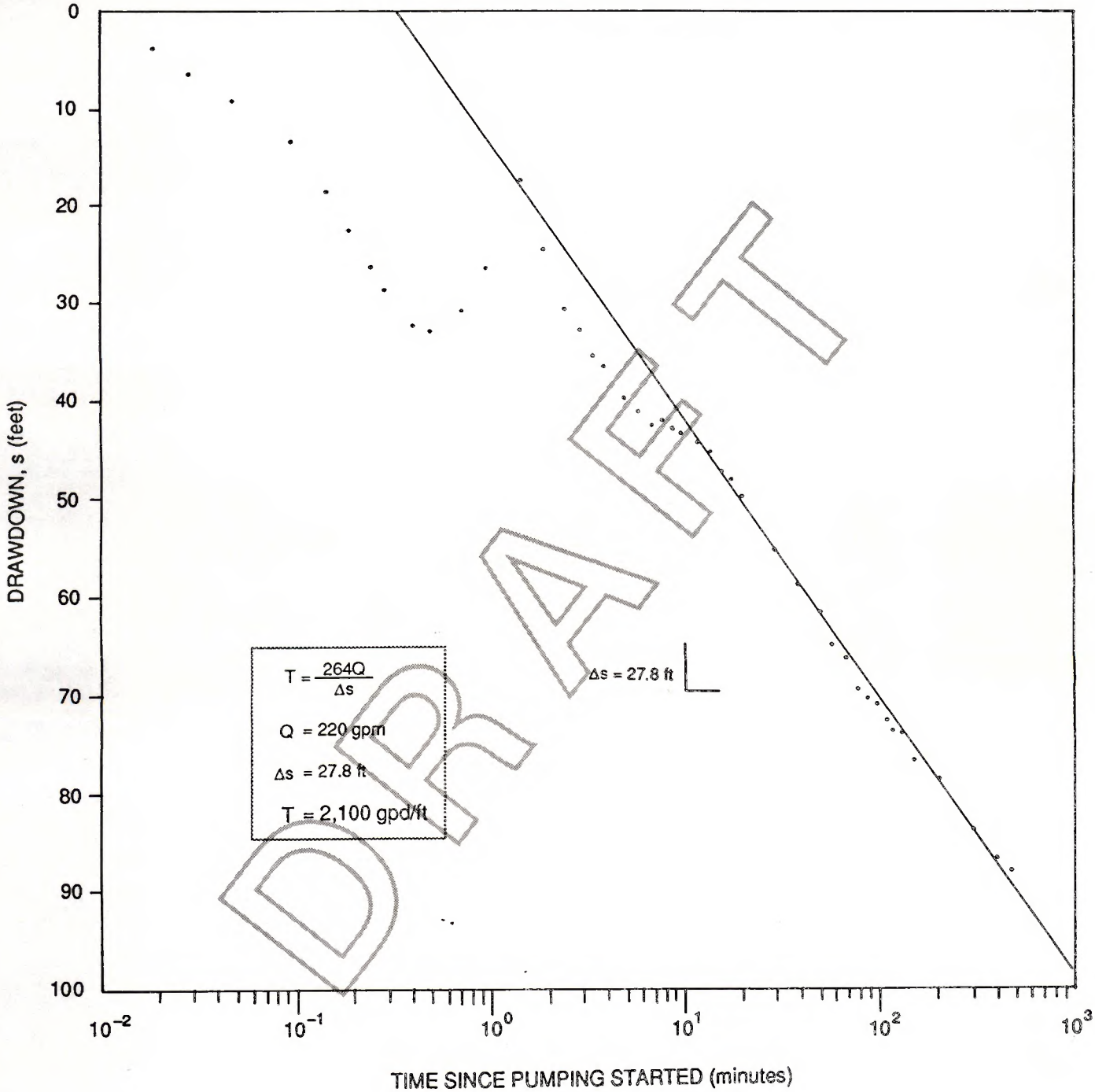
Figure 4-6

DRAFT

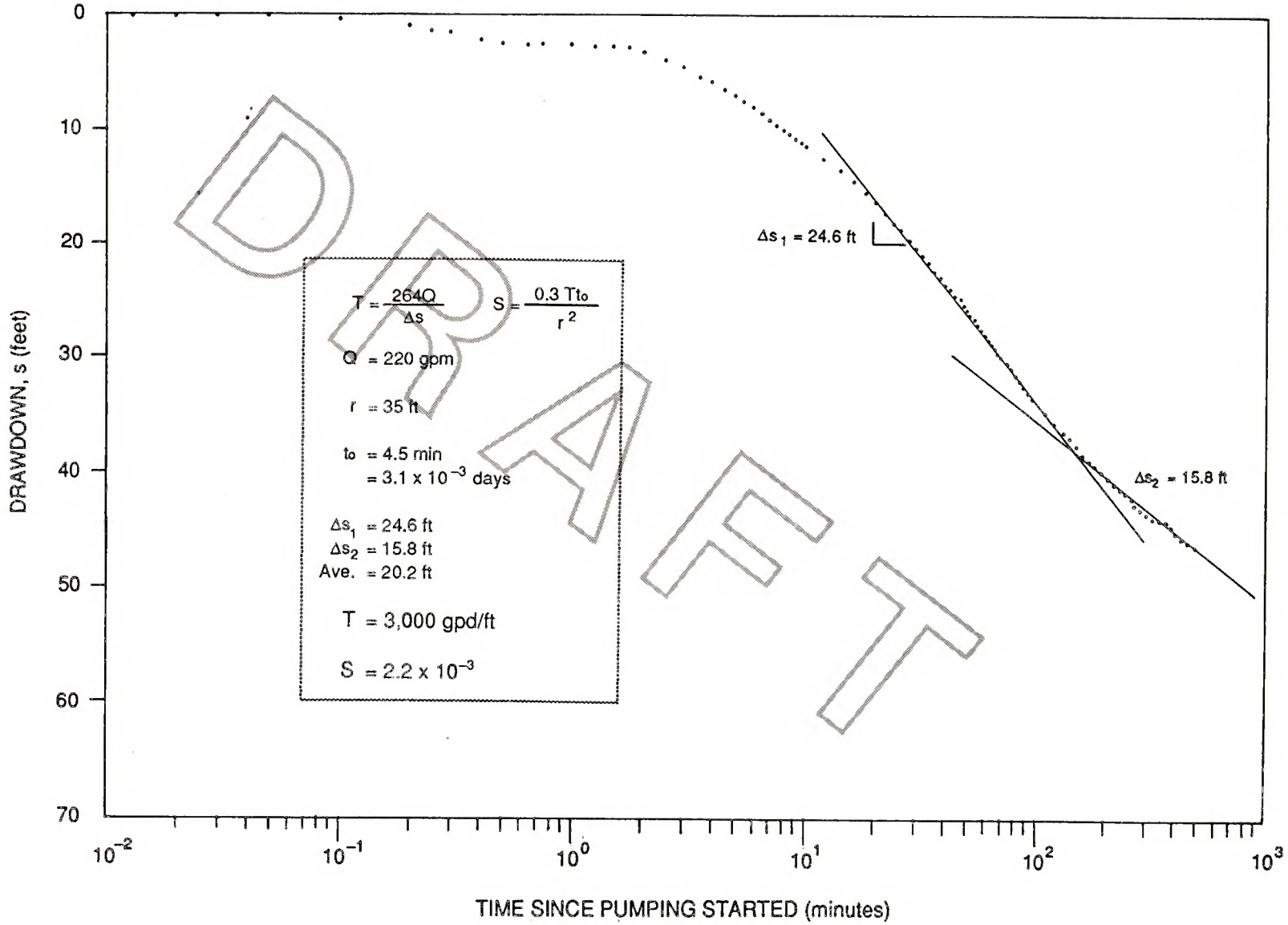


DRAFT

Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-1 COOPER-JACOB METHOD	Figure 4-7
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-3 COOPER-JACOB METHOD	Figure 4-8
Woodward-Clyde Consultants			



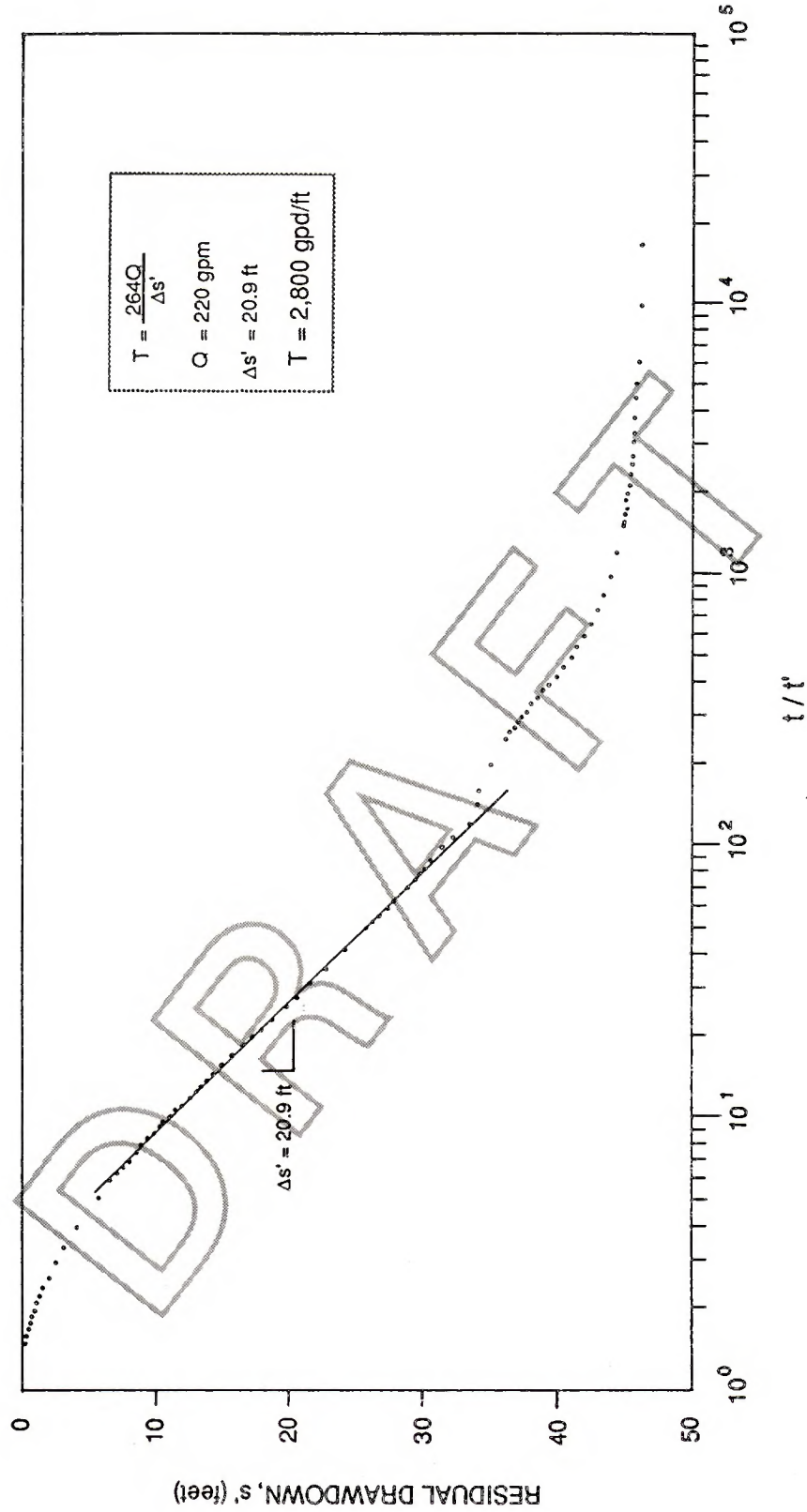
DRAWDOWN PLOT FOR MW-3
COOPER-JACOB METHOD

Figure 4-9

Project No. 90270B

Thousand Springs Power Plant

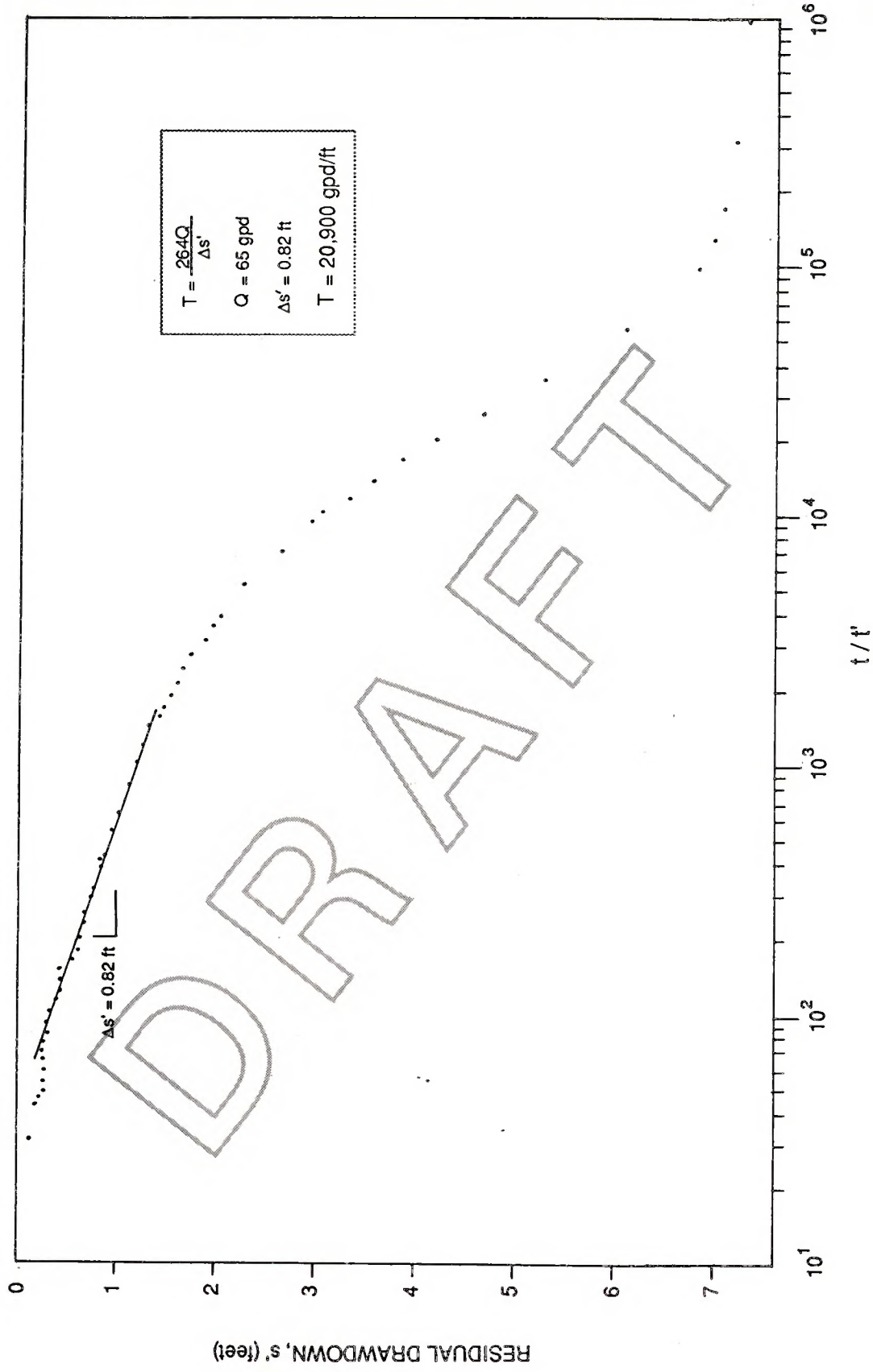
Woodward-Clyde Consultants



DRAFT

Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR MW-3 COOPER-JACOB METHOD	Figure 4-10
Woodward-Clyde Consultants			

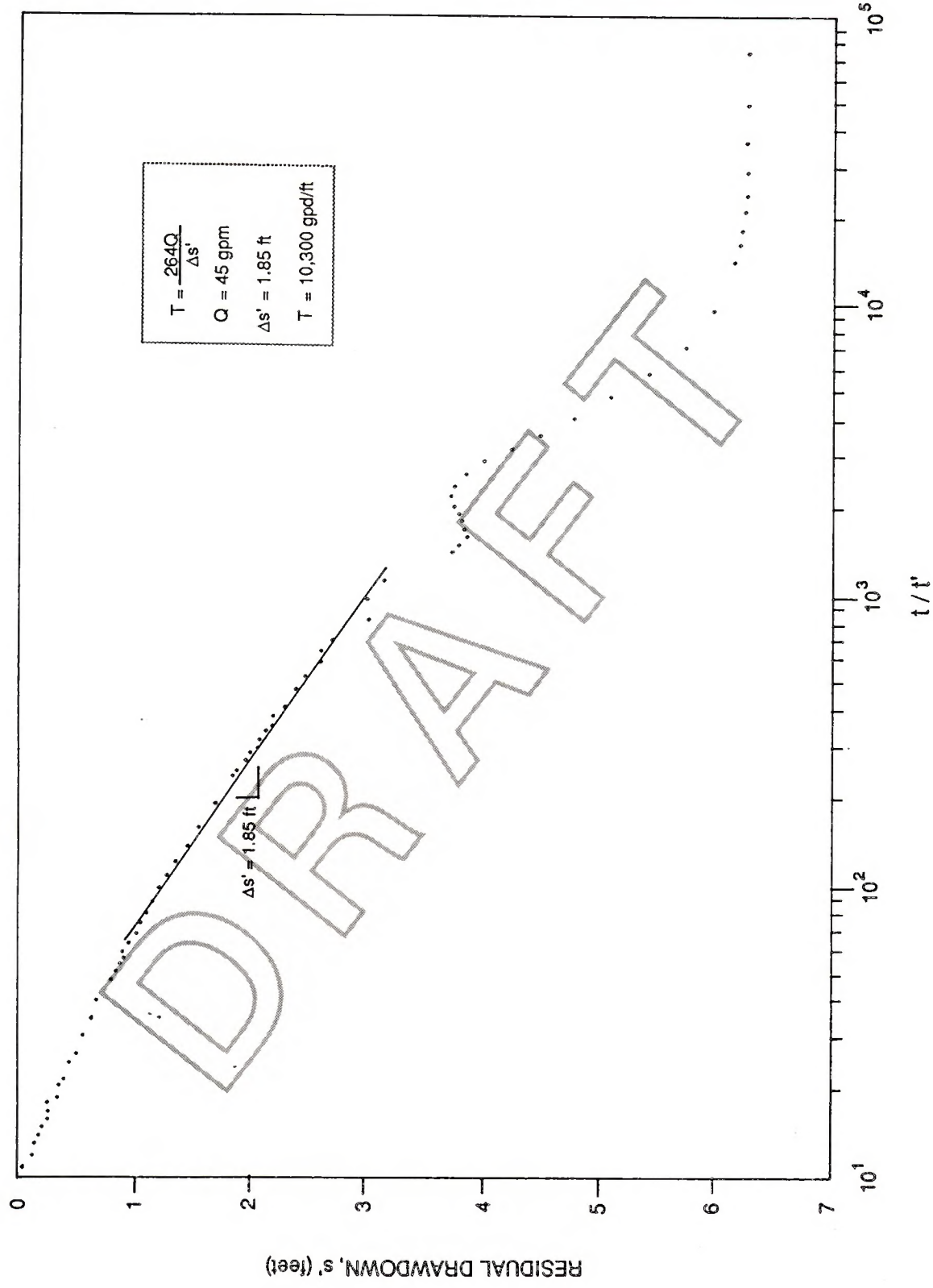
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-12 AND MW-12 COOPER-JACOB METHOD	Figure 4-11
Woodward-Clyde Consultants			



DRAFT

Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-12 COOPER-JACOB METHOD	Figure 4-12
Woodward-Clyde Consultants			

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-14 COOPER-JACOB METHOD	Figure 4-13
Woodward-Clyde Consultants			



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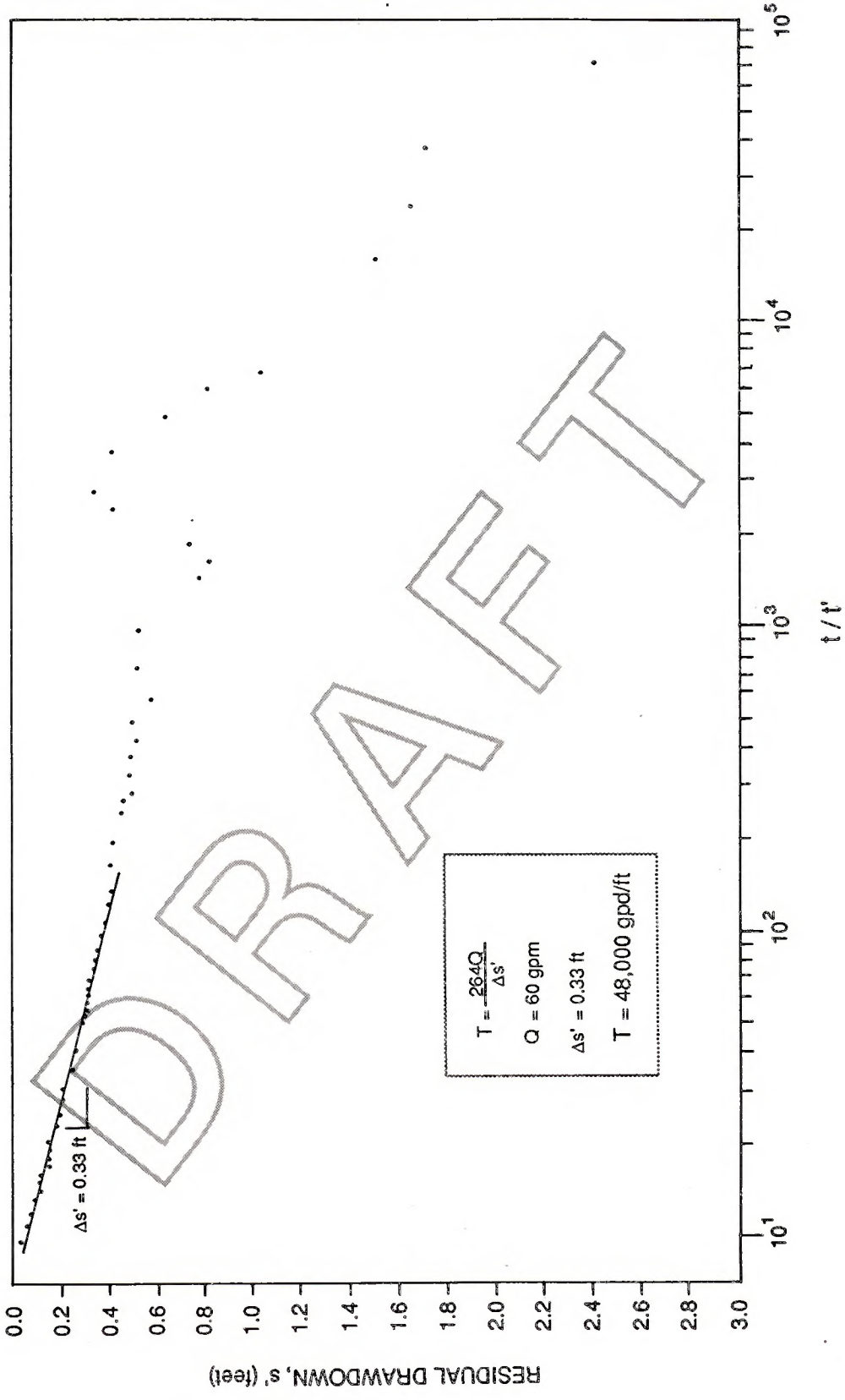
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-14 COOPER-JACOB METHOD	Figure 4-14
Woodward-Clyde Consultants			

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-15 COOPER-JACOB METHOD	Figure 4-15
Woodward-Clyde Consultants			



DRAFT

Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-15 COOPER-JACOB METHOD	Figure 4-16
Woodward-Clyde Consultants			

DRAFT

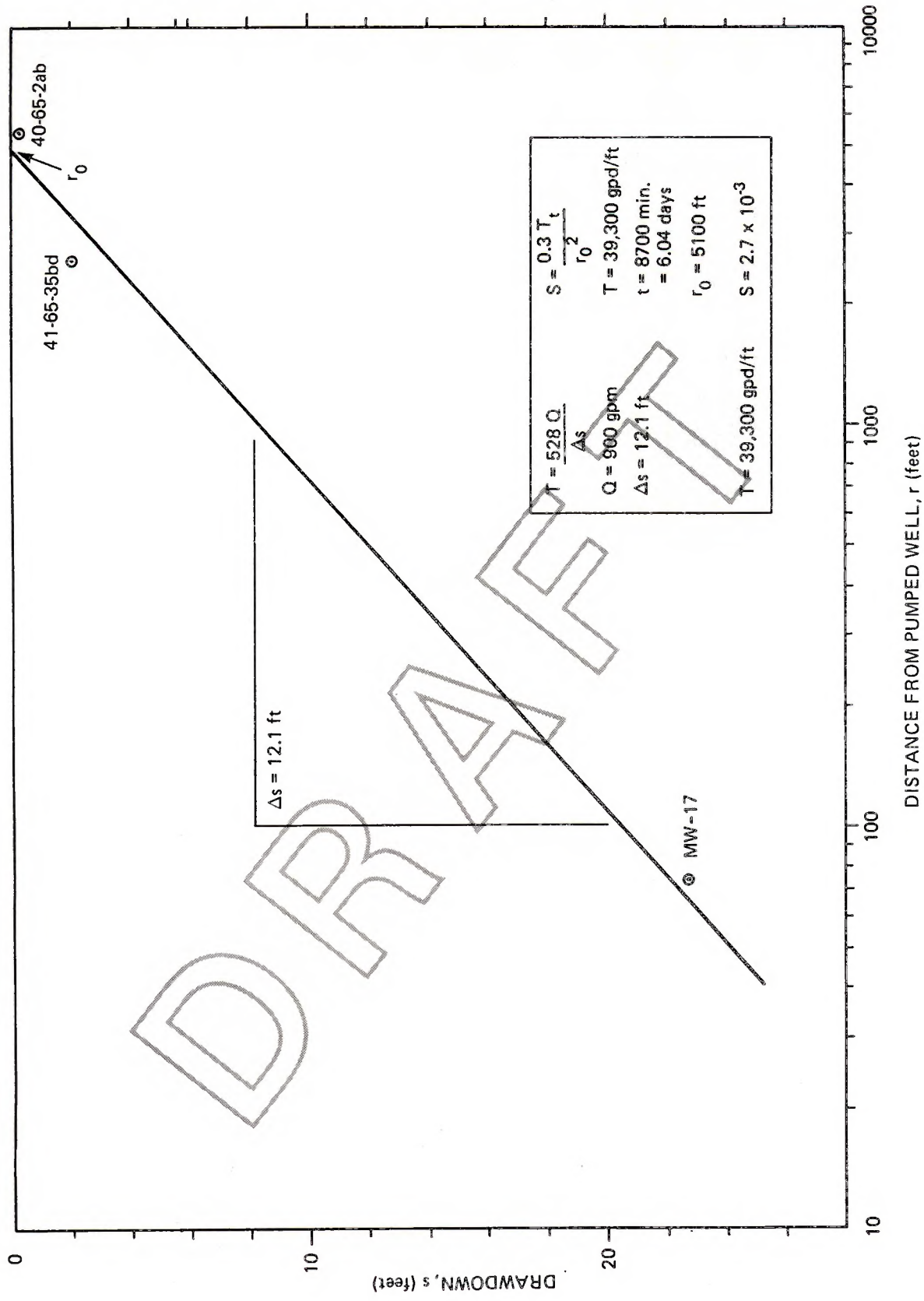
Project No. 90270B

Thousand Springs Power Plant

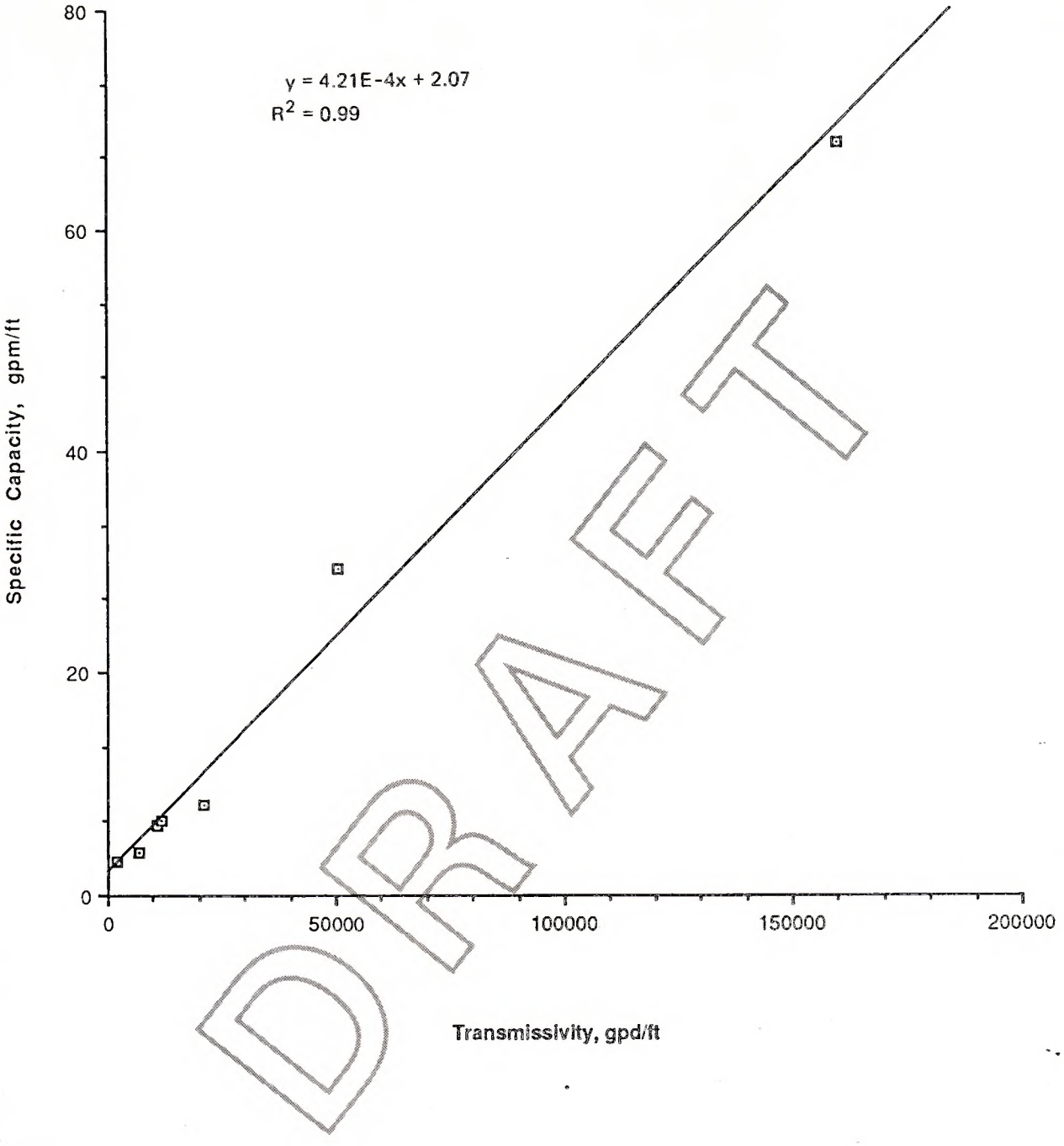
Woodward-Clyde Consultants

DRAWDOWN AND RECOVERY PLOT FOR MW-17

Figure 4-17



Project No. 90270B	Thousand Springs Power Plant	DISTANCE-DRAWDOWN PLOT OF MONITORING WELLS IN VICINITY OF WELL 41-65-35ad	Figure 4-18
Woodward-Clyde Consultants			



DRAFT

Project No. 90270B	Thousand Springs Power Plant	CORRELATION OF SPECIFIC CAPACITIES OF WELLS TO AQUIFER TRANSMISSIVITIES	Figure 4-19
Woodward-Clyde Consultants			

T43N

T42N

T41N

T40N

T39N

T38N

S10

S9

S11

MW-1

THOUSAND SPRINGS BASIN BOUNDARY

MW-4

25bb

S7

S8

22bc

35ad

TW-12

33ac

S6

S12

10ca

S5

PROPOSED THOUSAND SPRINGS POWER PLANT

24bd

S4

S3

MW-2

TW-3

S14

S13

TW-15

S15

S2

TW-14

S1

THOUSAND SPRINGS BASIN BOUNDARY

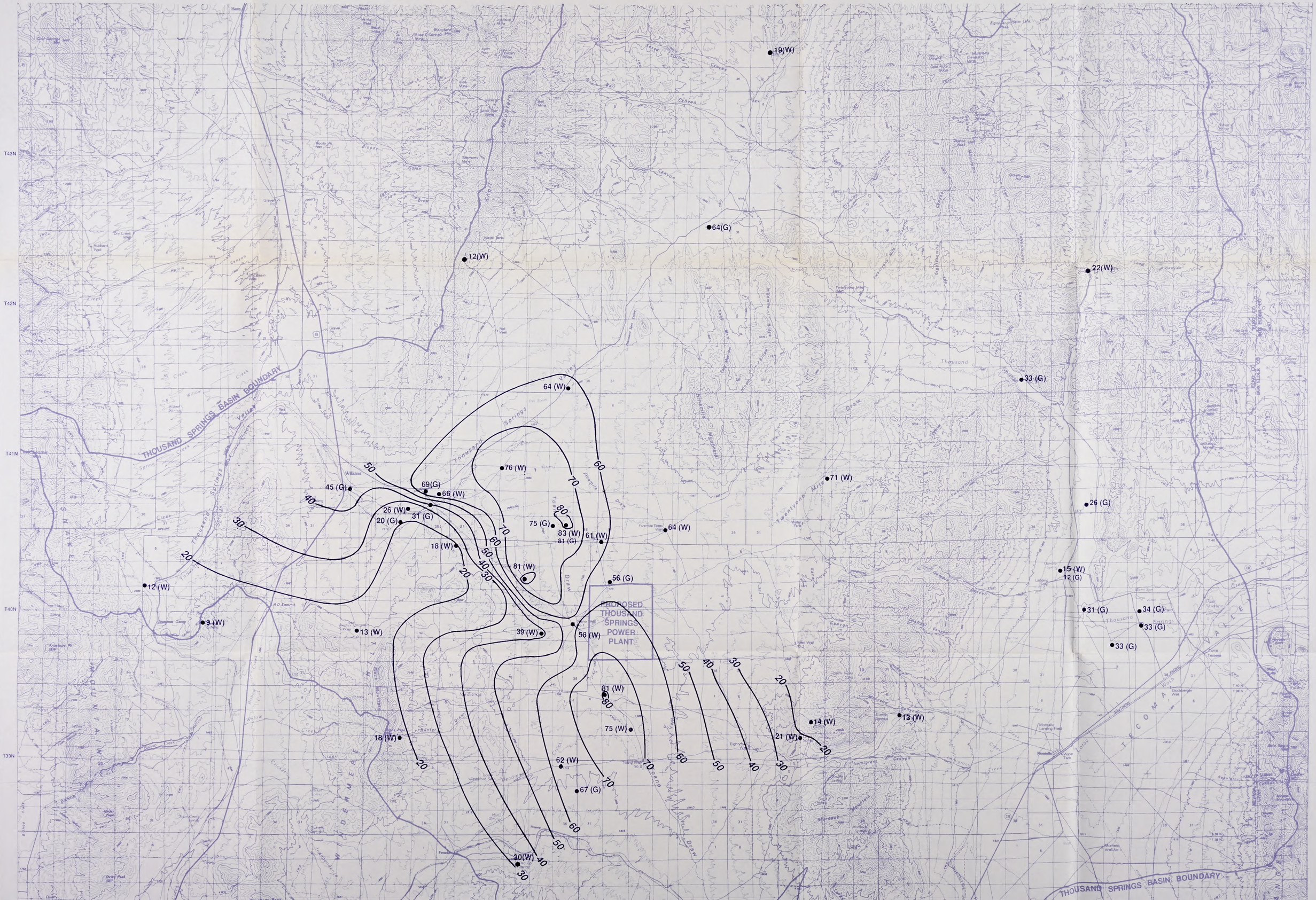
LEGEND

- ● Spring sampling location
- ▲ Well sampling location
- ○ Soil sampling location

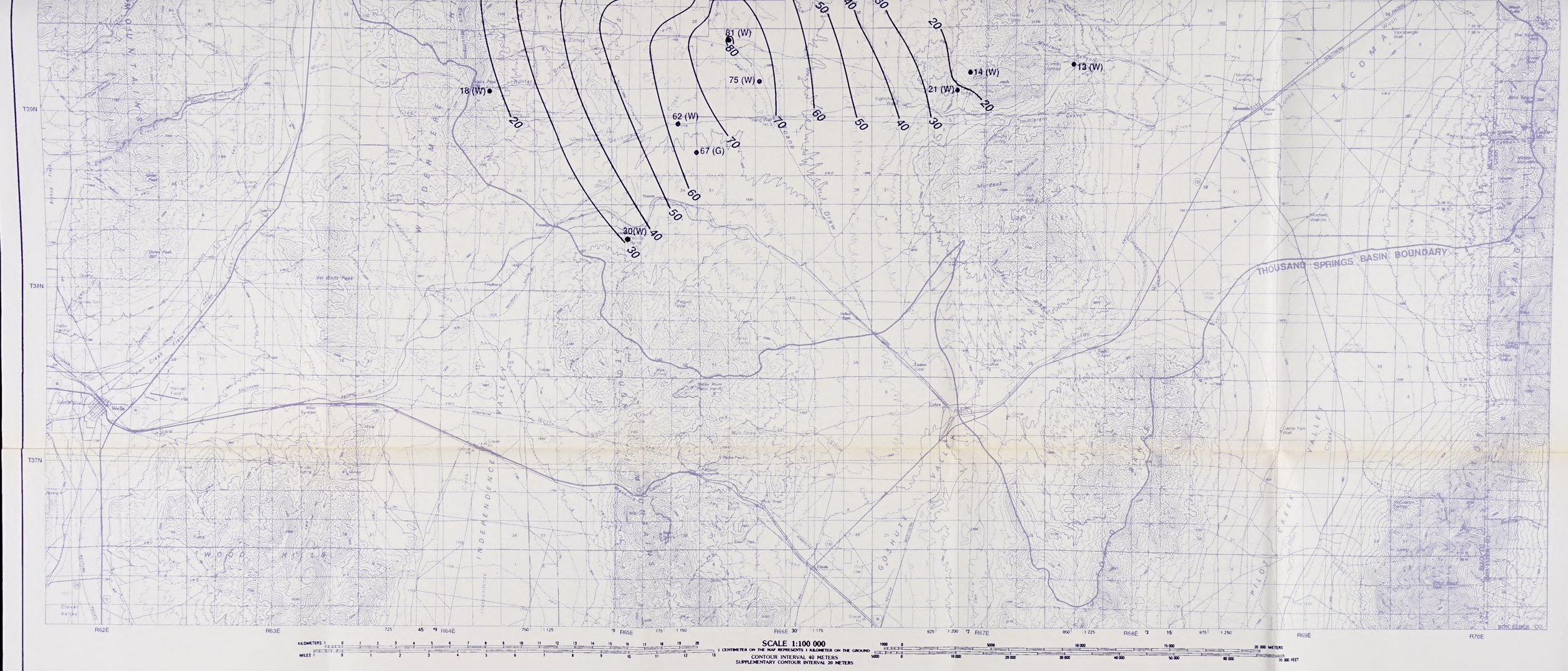
-N-

WELL, SPRING, AND SOIL SAMPLING LOCATION MAP

Project No. 90270B	Thousand Springs Power Plant	Figure 5-1
Woodward-Clyde Consultants		



19(W)
64(G)
12(W)
22(W)
33 (G)
64 (W)
76 (W)
71 (W)
45 (G)
69(G)
66 (W)
26 (W)
31 (G)
20 (G)
75 (G)
83 (W)
81 (G)
61 (W)
64 (W)
26 (G)
18 (W)
81 (W)
56 (G)
15 (W)
12 (G)
12 (W)
9 (W)
13 (W)
39 (W)
58 (W)
31 (G)
34 (G)
33 (G)
33 (G)
PROPOSED THOUSAND SPRINGS POWER PLANT
81 (W)
75 (W)
14 (W)
13 (W)
21 (W)
18 (W)
62 (W)
67 (G)
30(W)
THOUSAND SPRINGS BASIN BOUNDARY
THOUSAND SPRINGS BASIN BOUNDARY
T43N
T42N
T41N
T40N
T39N



LEGEND

——— Chemical isoconcentration contours. Contour interval is 10 mg/L

● (W) Analyses performed by WCC, 1988, values in mg/L

● (G) Analyses published or performed by W.F. Guyton & Assoc., May 1982, values in mg/L

-N-

SILICA (SiO_2) CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

Project No. 90270B	Thousand Springs Power Plant	Figure 5-2
Woodward-Clyde Consultants		

T43N
T42N
T41N
T40N
T39N
THOUSAND SPRINGS BASIN BOUNDARY
PROPOSED THOUSAND SPRINGS POWER PLANT
1110(W)
361(W)
228(W)
376 (W)
260 (W)
278 (G)
268 (W)
280 (W)
515(W)
361 (G)
398 (G)
308 (G)
330 (W)
316 (G)
187 (W)
920 (W)
193 (W)
330 (W)
208 (G)
224(W)
236(G)
173 (W)
8.0 (W)
103 (W)
421 (W)
310 (W)
240 (W)
203 (W)
285 (W)
327 (W)
304 (W)
2110(W)
229 (W)
212 (G)
344 (W)

LEGEND

——— Chemical isoconcentration contours. Contour interval is100 mg/L. Intermediate 50mg/L contour interval is dashed.

● (W) Analyses performed by WCC, 1988, values in mg/L

● (G) Analyses published or performed by W.F. Guyton & Assoc., May 1982, values in mg/L

N

TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

Project No. 90270B	Thousand Springs Power Plant	Figure 5-3
Woodward-Clyde Consultants		

T43N

T42N

T41N

T40N

T39N

THOUSAND SPRINGS BASIN BOUNDARY

PROPOSED THOUSAND SPRINGS POWER PLANT

10(W)

15(G)

10(W)

16(W)
18(G)

25(G)

8 (W)

9 (G)

14 (G)

13 (W)

21 (W)

30 (G)

10 (G)

21 (G)

24 (W)

17 (W)

19 (G)

11 (W)
14 (G)

7 (W)

9 (W)

6 (G)

24 (W)

64 (W)

7 (W)

4 (W)

6(W)

3 (W)

7 (W)

120 (W)

12 (W)

6 (G)

20 (W)

12 (W)
20 (G)

25(G)

21 (W)

20 (W)

20 (W)

19 (W)

12(W)
12(G)

51(G)

52(G)

116(G)

117(G)

121(G)

44(G)

85(G)

THOUSAND SPRINGS BASIN BOUNDARY

LEGEND

——— Contour of equal concentration of chloride in mg/L. Contour interval is 10 mg/L. Intermediate 5 mg/L contour interval line is dashed.

● (W) Analyses performed by WCC, 1988, values in mg/L

● (G) Analyses published or performed by W.F. Guyton & Assoc., May 1982, values in mg/L

-N-

CHLORIDE CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

Project No. 90270B	Thousand Springs Power Plant	Figure 5-4
Woodward-Clyde Consultants		

Contact

Rock Springs Creek

Lower Eccles

Eccles Narrows

Narrows

Twenty-One Mile Reservoir

Twenty-One Mile Junction

Shores

Lower Schoolhouse

Crittenden Creek

Twelve Mile

BASIN BOUNDARY

T47N

T46N

T45N

T44N

T43N

T42N

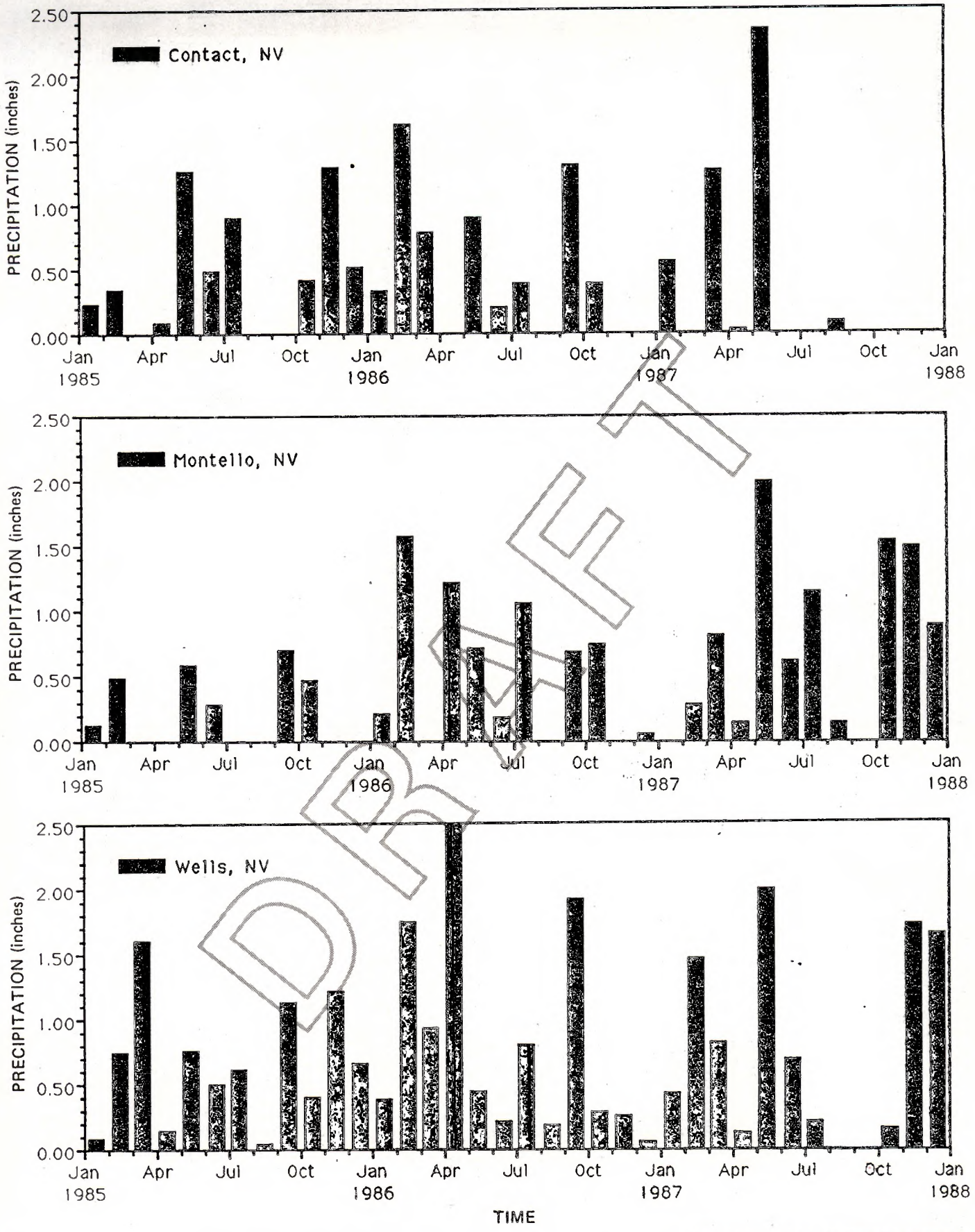
LEGEND

- ▲ Streamflow Station
- ● Precipitation Station
- ■ Reservoir Station
- ○△ Discontinued Station

Note: Published data stations (BLM, NOAA, USGS) are underlined.
Unpublished data stations (Kennedy/Jenks/Chilton) are not underlined.

STREAMFLOW, PRECIPITATION AND RESERVOIR MONITORING STATIONS

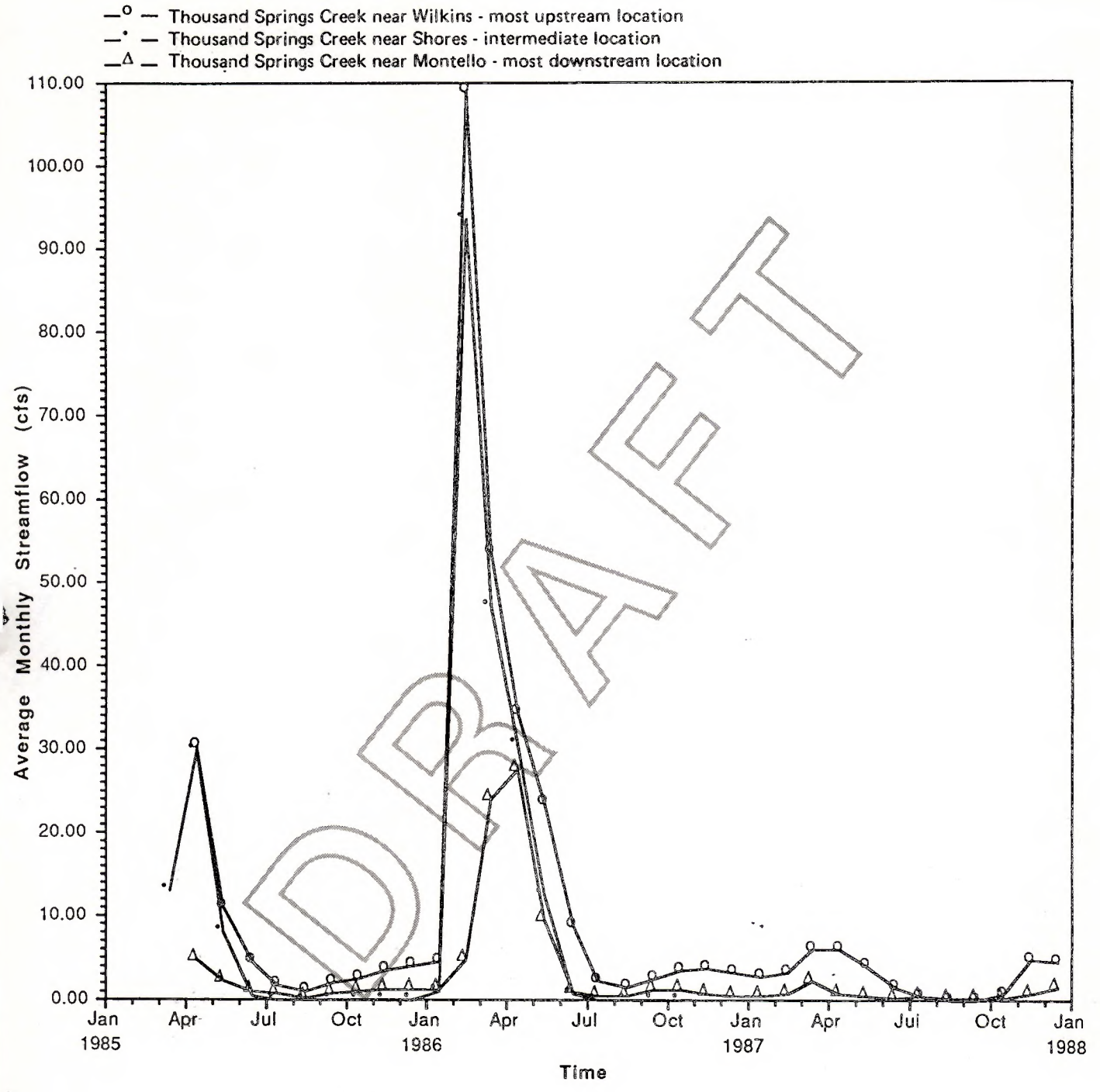
Project No. 90270B	Thousand Springs Power Plant	Figure 6-1
Woodward-Clyde Consultants		



DRAFT

Data provided by Chilton Engineering.

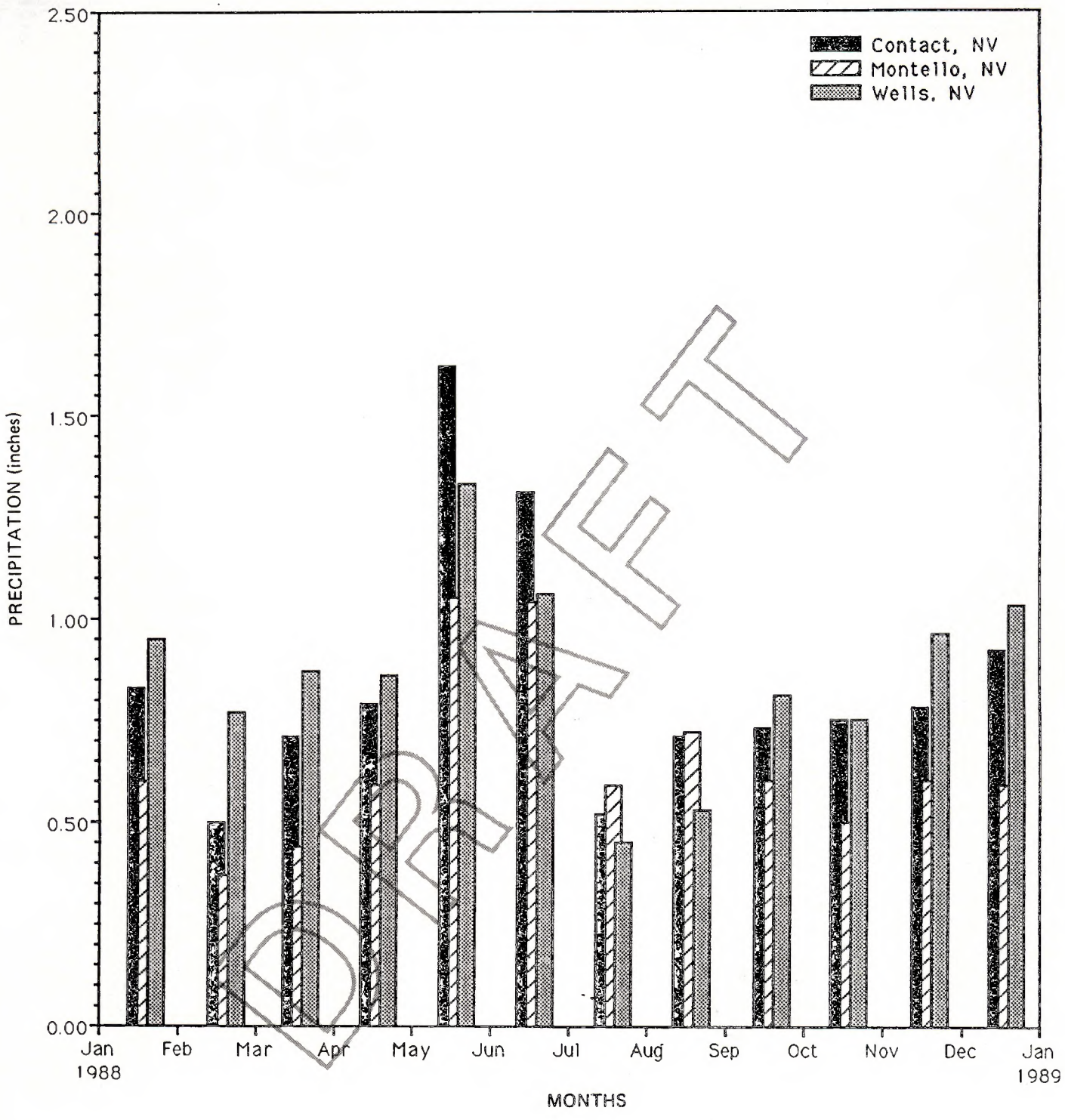
Project No. 90270B	Thousand Springs Power Plant	TOTAL MONTHLY PRECIPITATION AT CONTACT, MONTELLO, AND WELLS MONITORING STATIONS, 1985 - 1987	Figure 6-2
Woodward-Clyde Consultants			



DRAFT

Data Provided by USGS

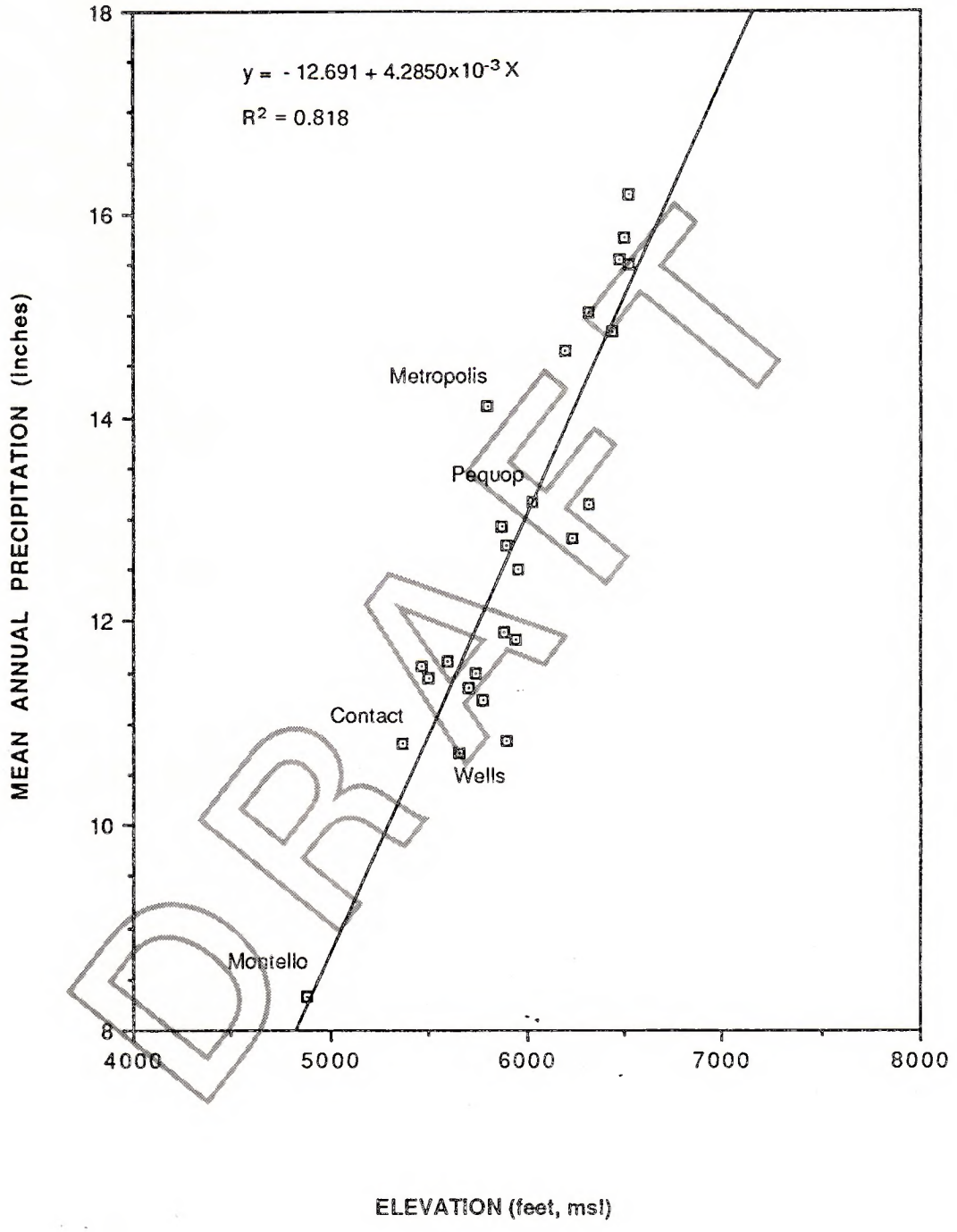
Project No. 90270B	Thousand Springs Power Plant	AVERAGE MONTHLY STREAMFLOW AT WILKINS, SHORES, AND MONTELLO GAGING STATIONS, 1985-1987	Figure 6-3
Woodward-Clyde Consultants			



DRAFT

Compiled by Woodward-Clyde Consultants from Data Provided by NOAA

Project No. 90270B	Thousand Springs Power Plant	AVERAGE MONTHLY PRECIPITATION AT CONTACT. MONTELLO, AND WELLS MONITORING STATIONS, 1949-1983	Figure 6-4
Woodward-Clyde Consultants			



DRAFT

Orographic analysis performed by Woodward-Clyde Consultants based on NOAA and BLM data

Project No. 90270B	Thousand Springs Power Plant	MEAN ANNUAL PRECIPITATION VERSUS ELEVATION AT NOAA AND BLM STATIONS 1963 – 1980	Figure 6-5
Woodward-Clyde Consultants			

LEGEND

▲ Streamflow stations

● Precipitation stations

Elevation Zones

- 1400 – 1520 m
- 1520 – 1640 m
- 1640 – 1760 m
- 1760 – 1880 m
- 1880 – 2000 m
- 2000 – 2120 m
- 2120 – 2240 m
- 2240 – 2360 m
- 2360 – 2480 m
- 2480 – 2600 m
- 2600 – 2720 m

100 m = 328 ft

Contact

93

Thiessen Polygon Boundary

Thousand Springs Creek

Twenty One Mile Reservoir

Downstream Limit of Drainage Basin of Shores Gaging Station

Downstream Limit of Drainage Basin of Wilkins Gaging Station

Downstream Limit of Drainage Basin below Crittenden Creek

Shores

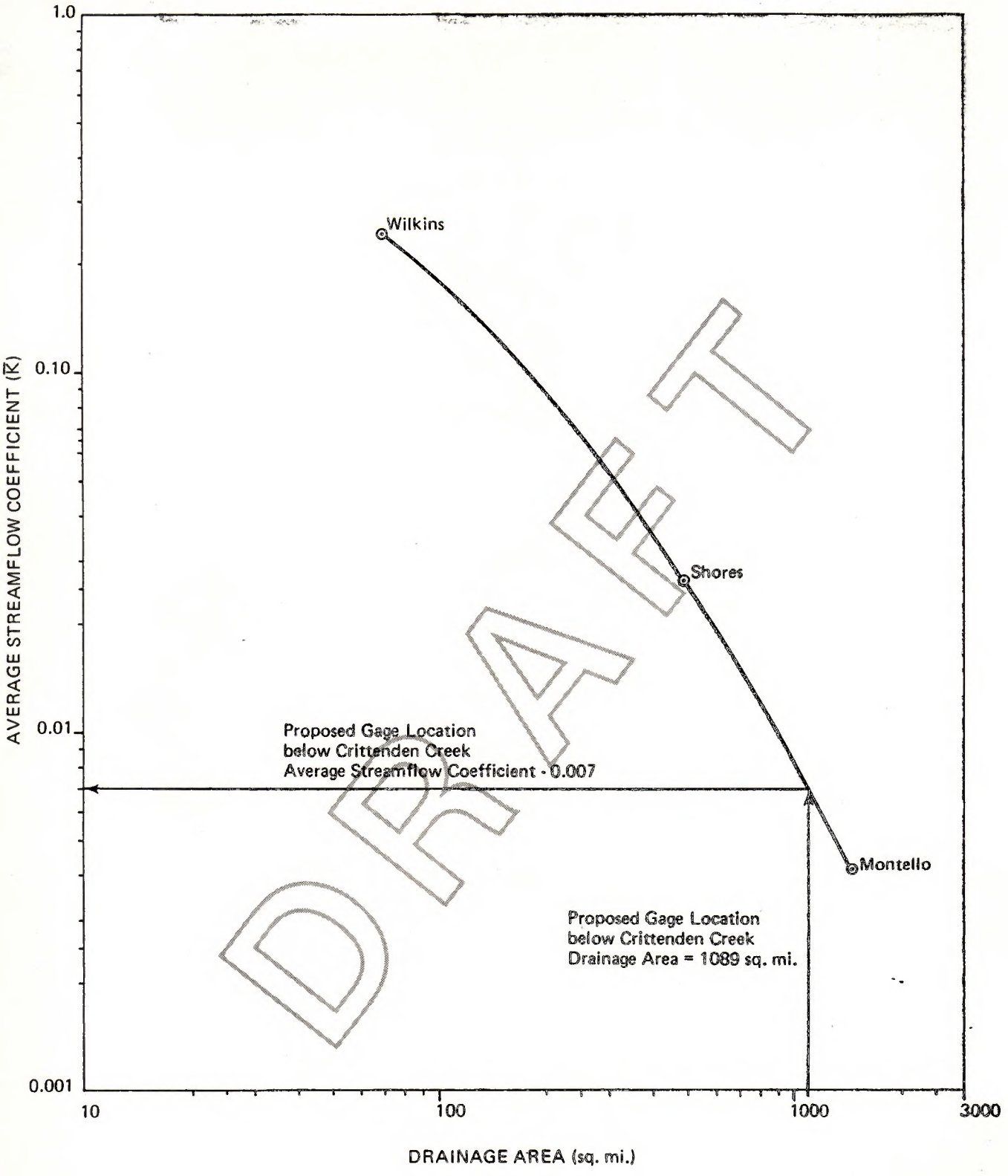
Wilkins

Thiessen Polygon Boundary

Downstream Limit of Tonne Draw Drainage Basin

Thousand Springs Creek

Montello



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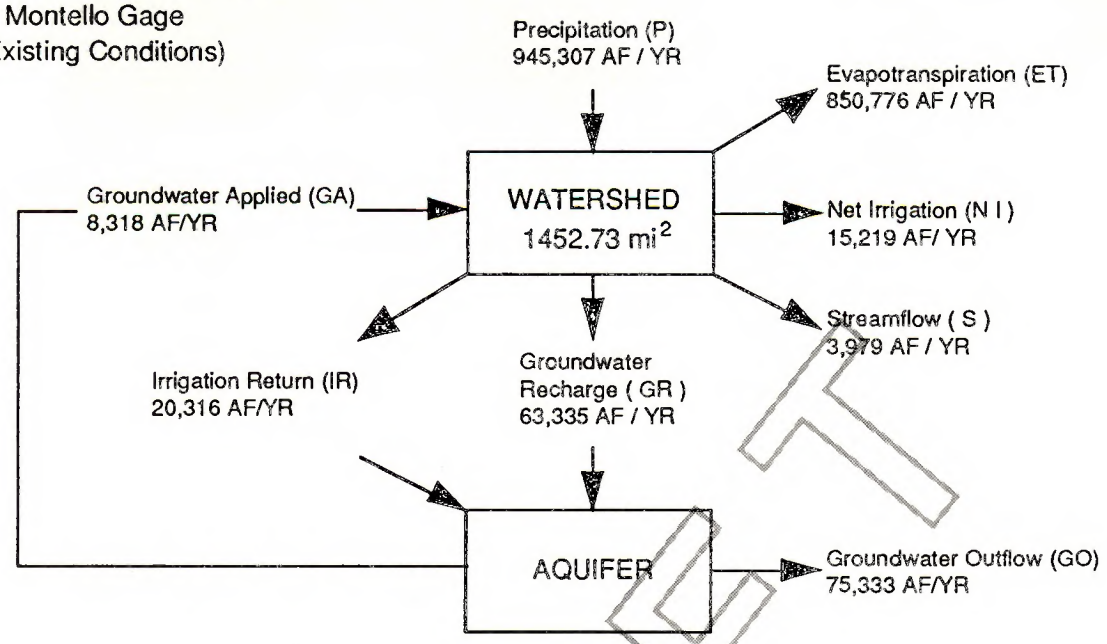
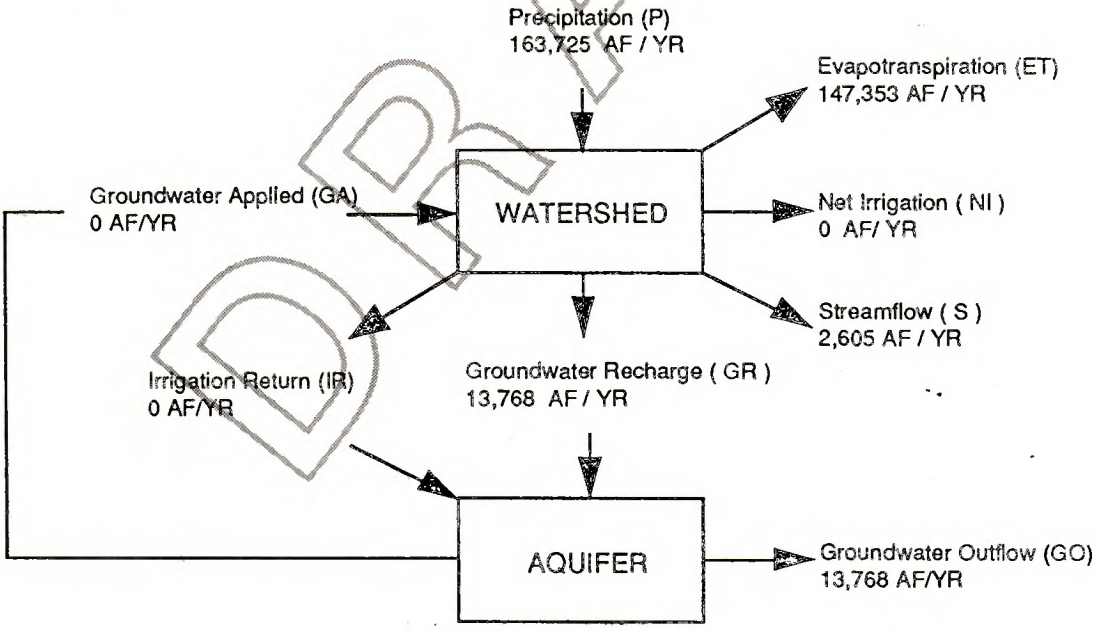
Project No. 90270B	Thousand Springs Power Plant	AVERAGE STREAMFLOW COEFFICIENT VERSUS DRAINAGE AREA FOR THOUSAND SPRINGS CREEK	Figure 6-7
Woodward-Clyde Consultants			

Thousand Springs Creek
at Montello Gage
(Existing Conditions)



Toano Draw at
Thousand Springs Creek



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Project No. 90270B	Thousand Springs Power Plant	HYDROLOGIC BUDGET FOR THOUSAND SPRINGS CREEK AND TOANO DRAW	Figure 6-8
Woodward-Clyde Consultants			

Drainage Basin of Wilkins Gaging Station

Thiessen Polygon Boundary

Wilkins

Thousand Springs Creek

Shores

Downstream Limit of Toano Draw Drainage Basin

Drainage Basin below Crittenden Creek

Thousand Springs Creek

Montello

Dake Reservoir

Montello

Thiessen Polygon Boundary

93

80

Wells

80

Limit of Thousand Springs Creek Drainage Basin

N

0 10,000 20,000

feet

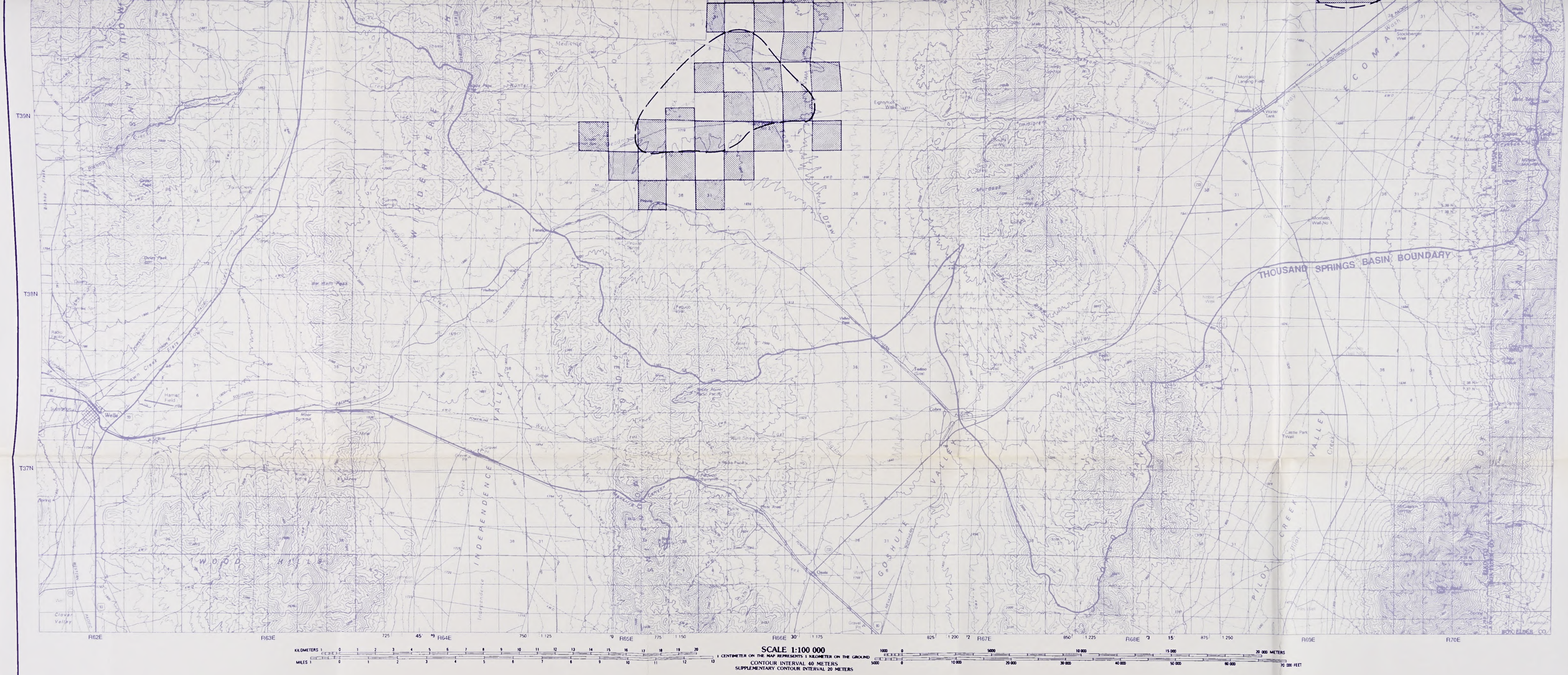
DRAINAGE BASIN MODEL

Project No. 90270B	Thousand Springs Power Plant	Figure 6-6
Woodward-Clyde Consultants		

PROPOSED THOUSAND SPRINGS POWER PLANT

THOUSAND SPRINGS BASIN BOUNDARY

T.9N.
T.8N.
T.7N.
T.6N.
T.5N.
T.4N.
T.3N.



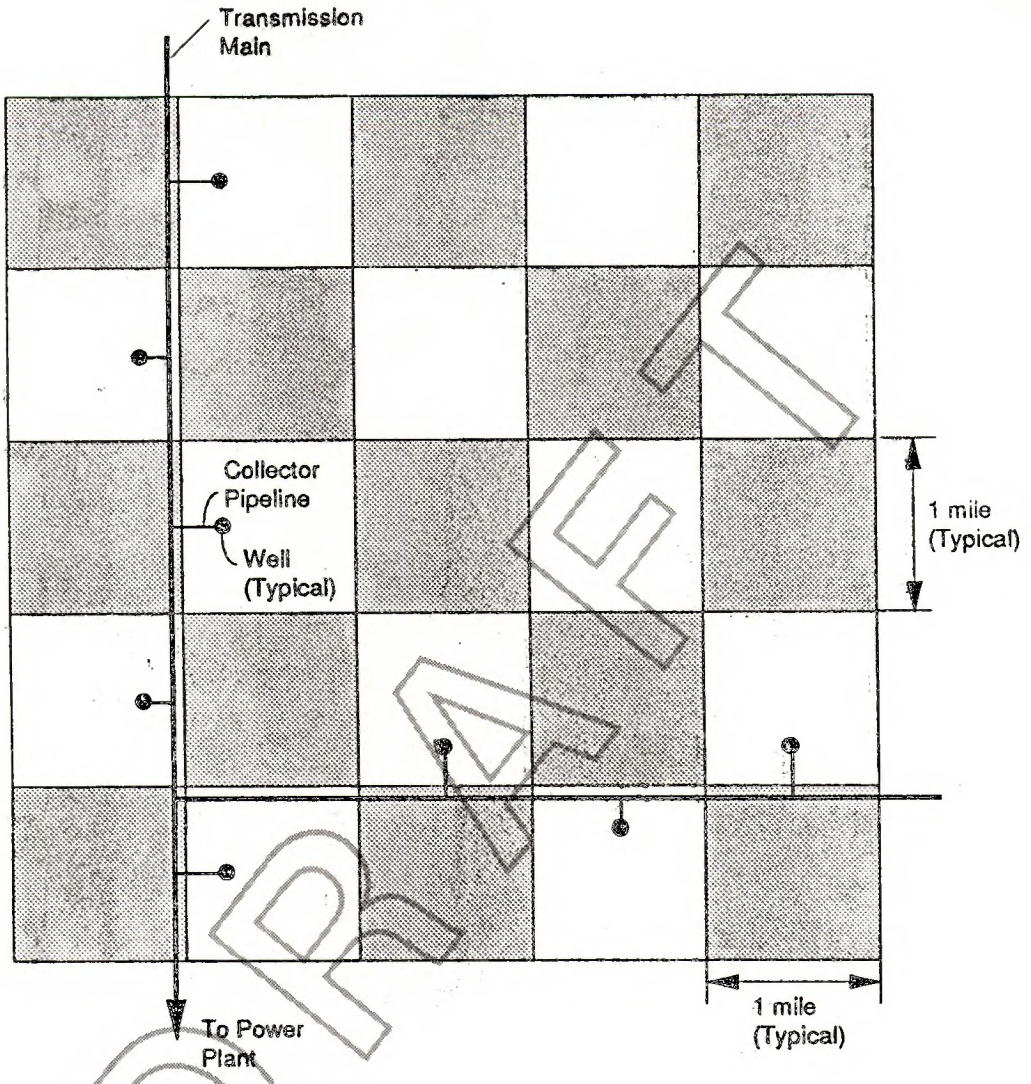
LEGEND

Lands owned by Lands of Sierra, Inc.

Outlines of areas where hydrogeological conditions appear favorable for well field development

POTENTIALLY FAVORABLE AREAS FOR WELL FIELDS TO SUPPLY POWER PLANT

Project No. 90270B	Thousand Springs Power Plant	Figure 7-1
Woodward-Clyde Consultants		



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Notes: Shaded sections are Public Lands administered by the BLM. Open sections owned by Lands of Sierra, Inc.

Actual well locations in selected sections will be based on results of detailed geophysical surveys and pilot borings

Project No. 90270B	Thousand Springs Power Plant	SCHEMATIC LAYOUT OF A WELL FIELD	Figure 7-2
Woodward-Clyde Consultants			

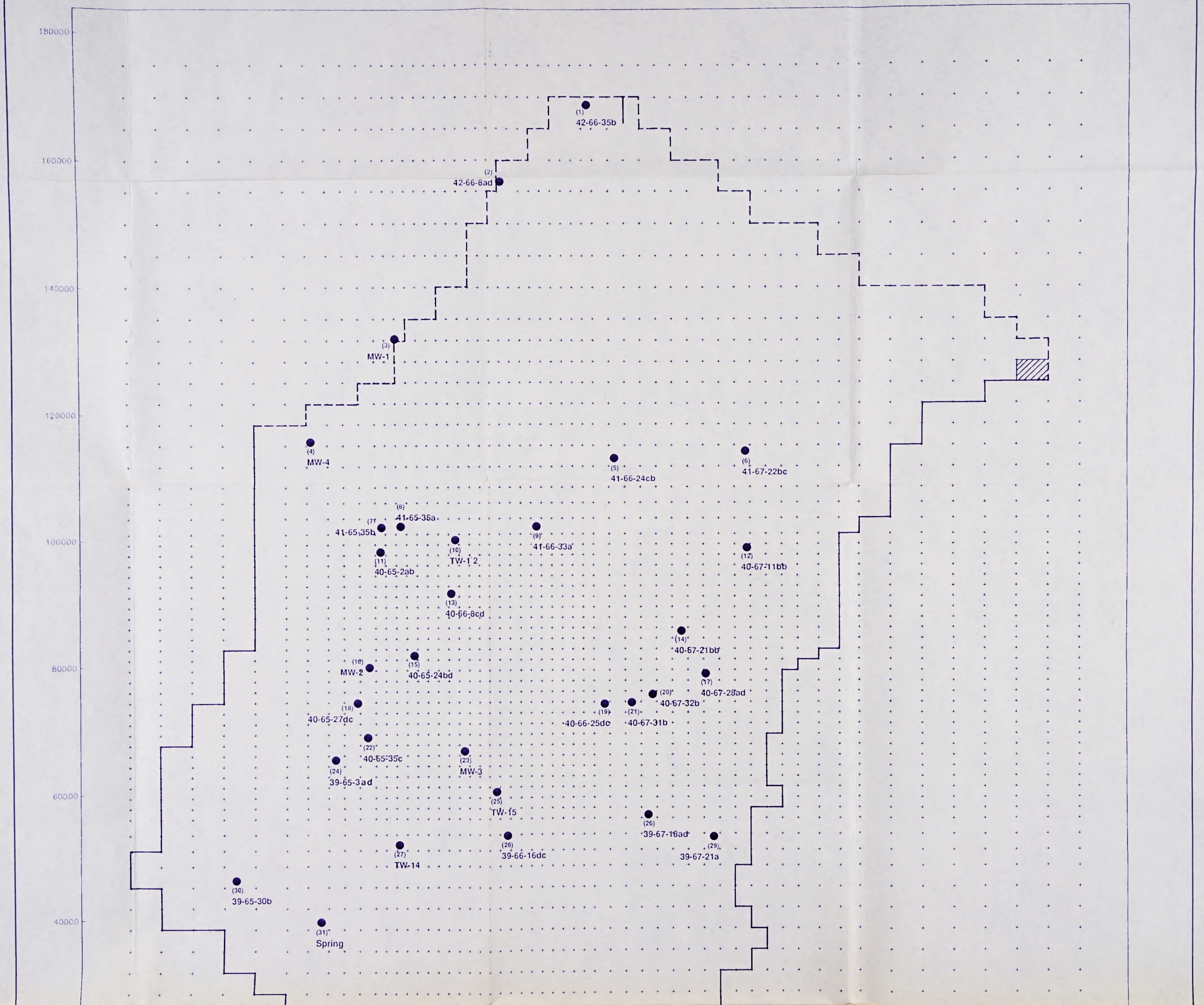
MODEL AREA BOUNDARY

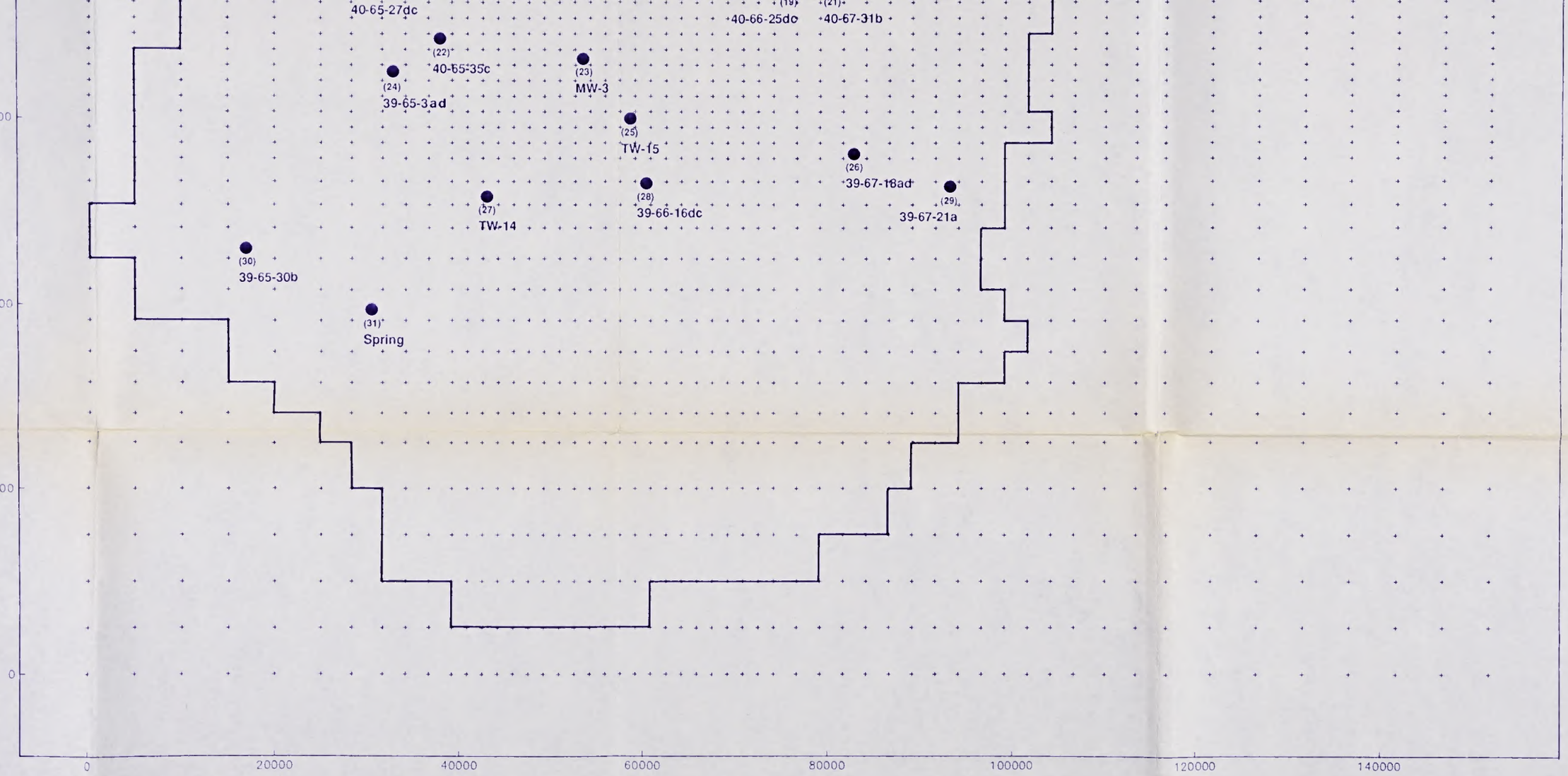
THOUSAND SPRINGS BASIN BOUNDARY

PROPOSED THOUSAND SPRINGS POWER PLANT

LOCATION OF THE MODEL AREA

Project No. 90270B	Thousand Springs Power Plant	Figure 8-1
Woodward-Clyde Consultants		


180000
160000
140000
120000
100000
80000
60000
40000
(1)
42-66-35b
(2)
42-66-8ad
(3)
MW-1
(4)
MW-4
(5)
41-66-24cb
(6)
41-67-22bc
(8)
41-65-35a
(7)
41-65-35b
(9)
41-66-33a
(10)
TW-1 2
(11)
40-65-2ab
(12)
40-67-11bb
(13)
40-66-8cd
(14)
40-67-21bb
(16)
MW-2
(15)
40-65-24bd
(17)
40-67-28ad
(18)
40-65-27dc
(19)
40-66-25dc
(20)
40-67-32b
(21)
40-67-31b
(22)
40-65-35c
(23)
MW-3
(24)
39-65-3ad
(25)
TW-15
(26)
39-67-16ad
(27)
TW-14
(28)
39-66-16dc
(29)
39-67-21a
(30)
39-65-30b
(31)
Spring



LEGEND

(3) MW-1 — Serial number of observation well; Well ID number

Constant head boundary

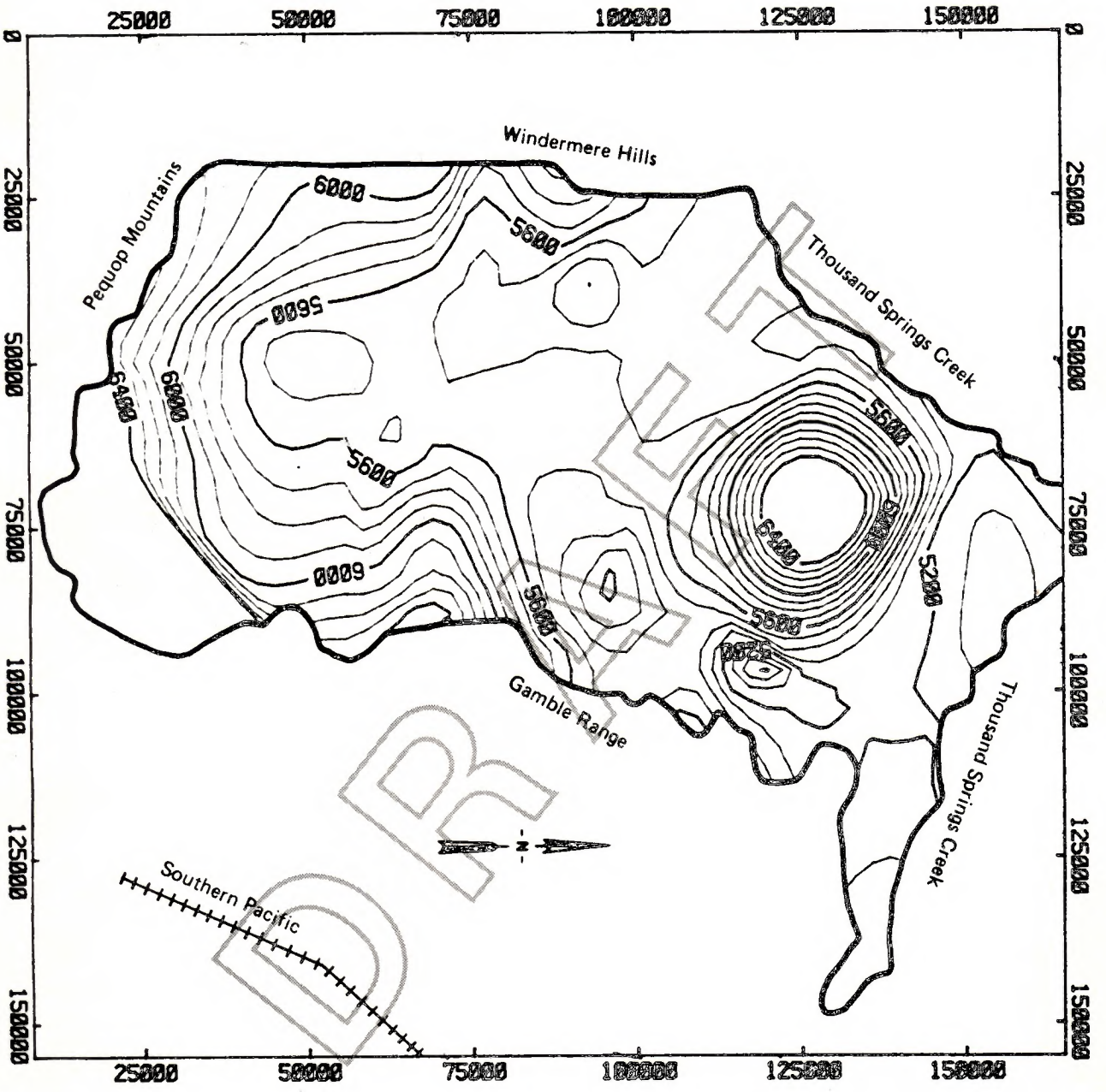
No flow boundary

Flow boundary

\+ Discretization node

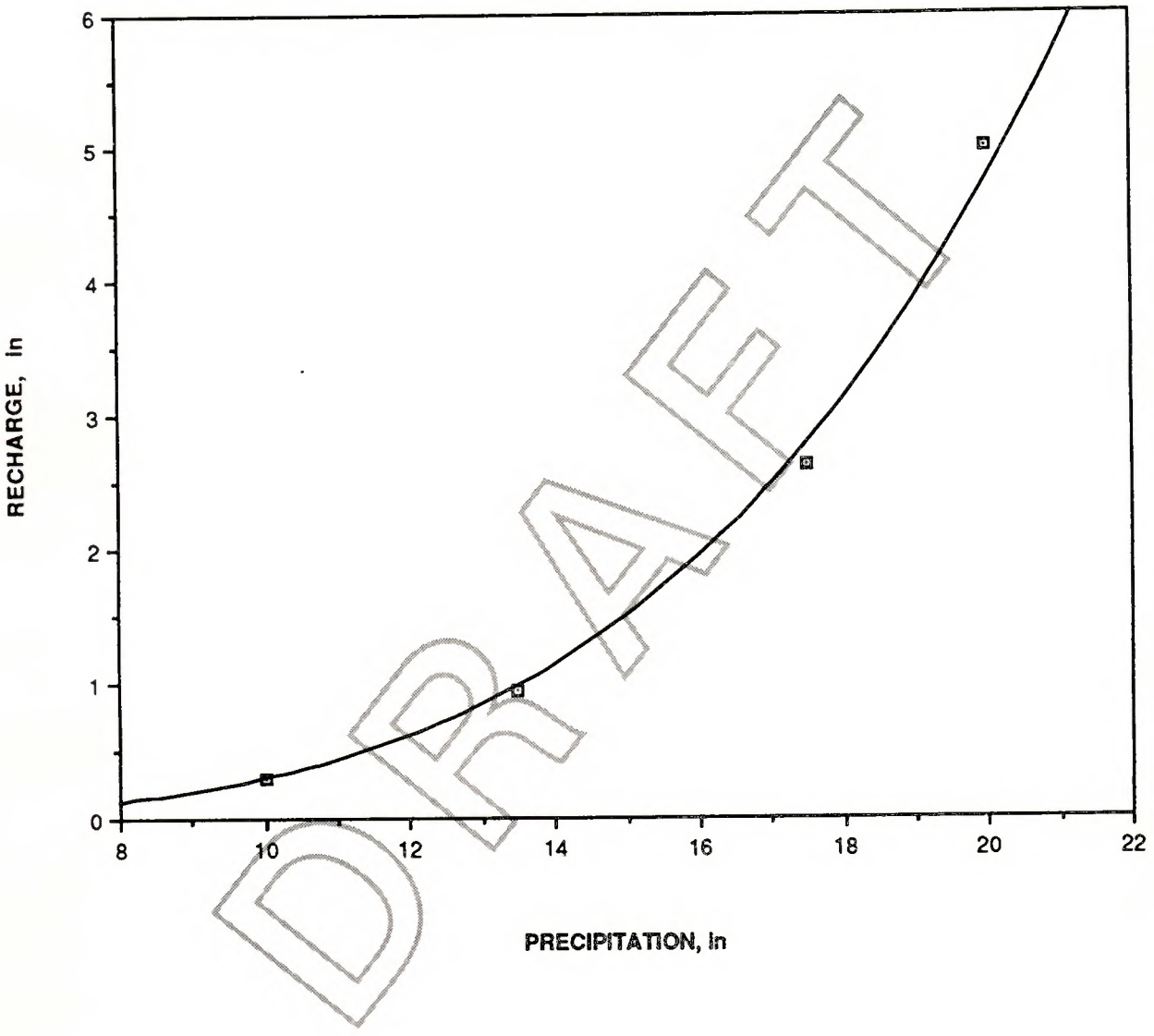
BOUNDARY CONDITIONS, SPATIAL DISCRETIZATION, AND LOCATION OF OBSERVATION WELLS

Project No. 90270B	Thousand Springs Power Plant	Figure 8-2
Woodward-Clyde Consultants		



Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP BASED ON AVAILABLE DATA	Figure 8-3
Woodward-Clyde Consultants			



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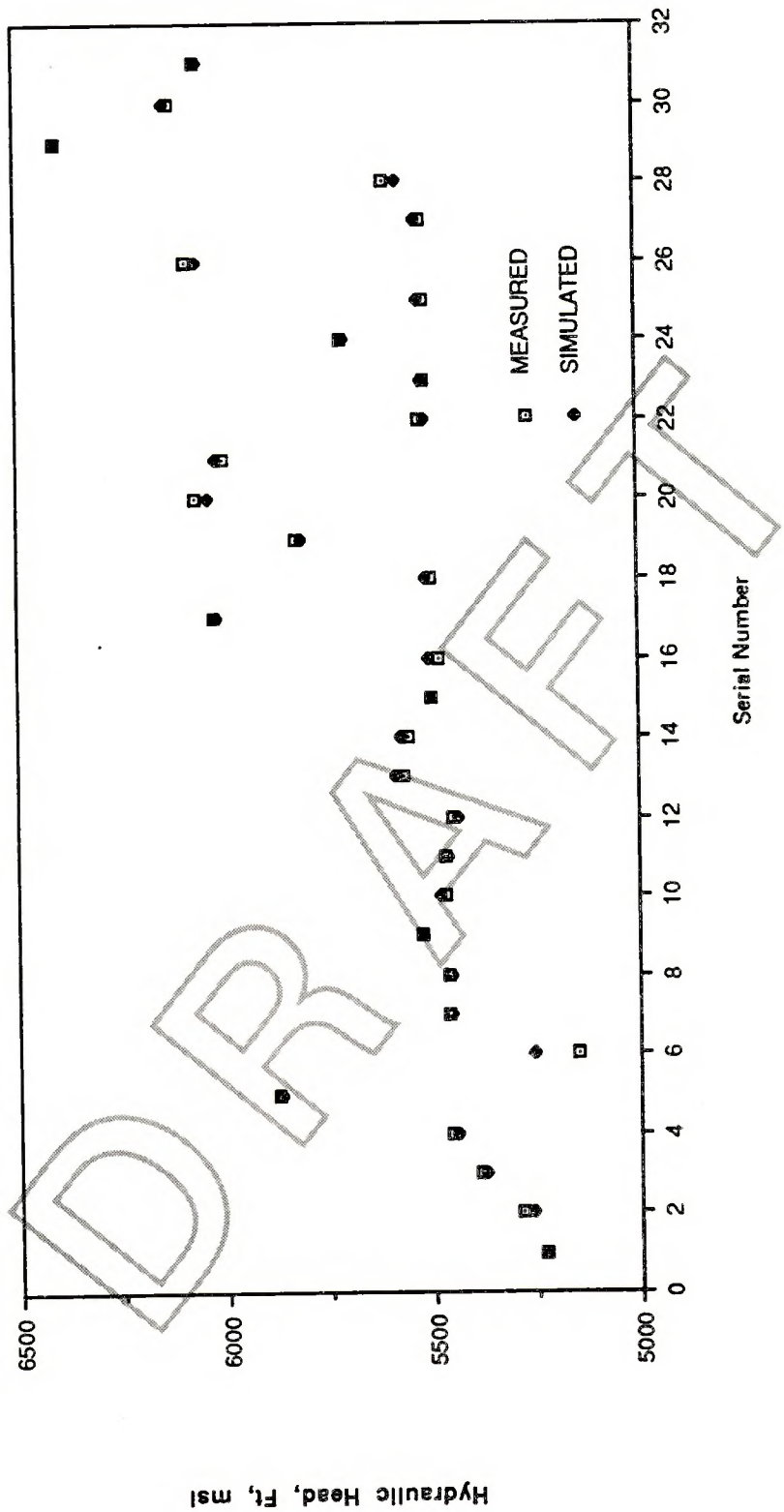
Project No. 90270B	Thousand Springs Power plant	RELATIONSHIP BETWEEN RECHARGE AND PRECIPITATION (MAXEY-EAKIN METHOD)	Figure 8-4
Woodward-Clyde Consultants			



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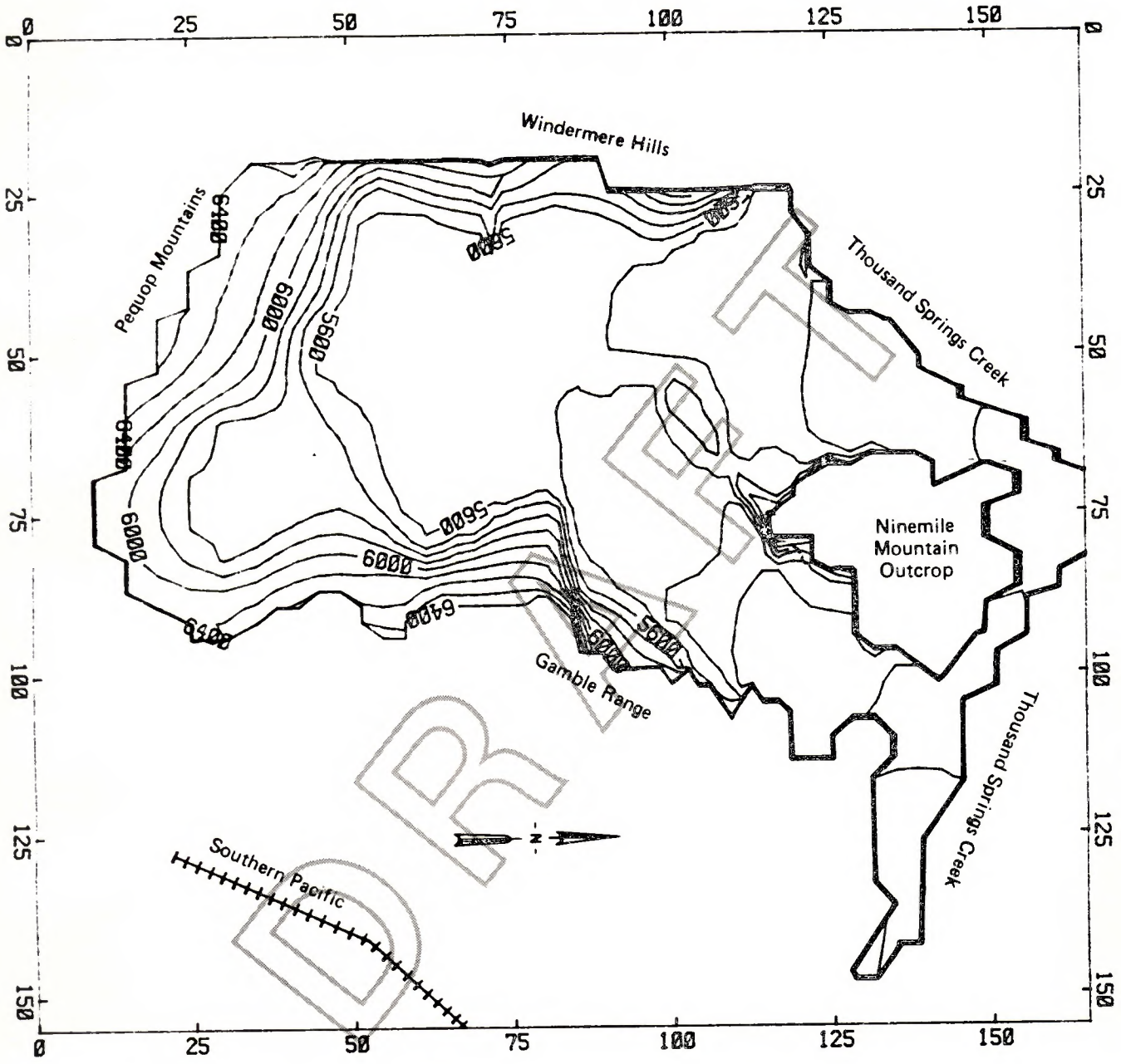
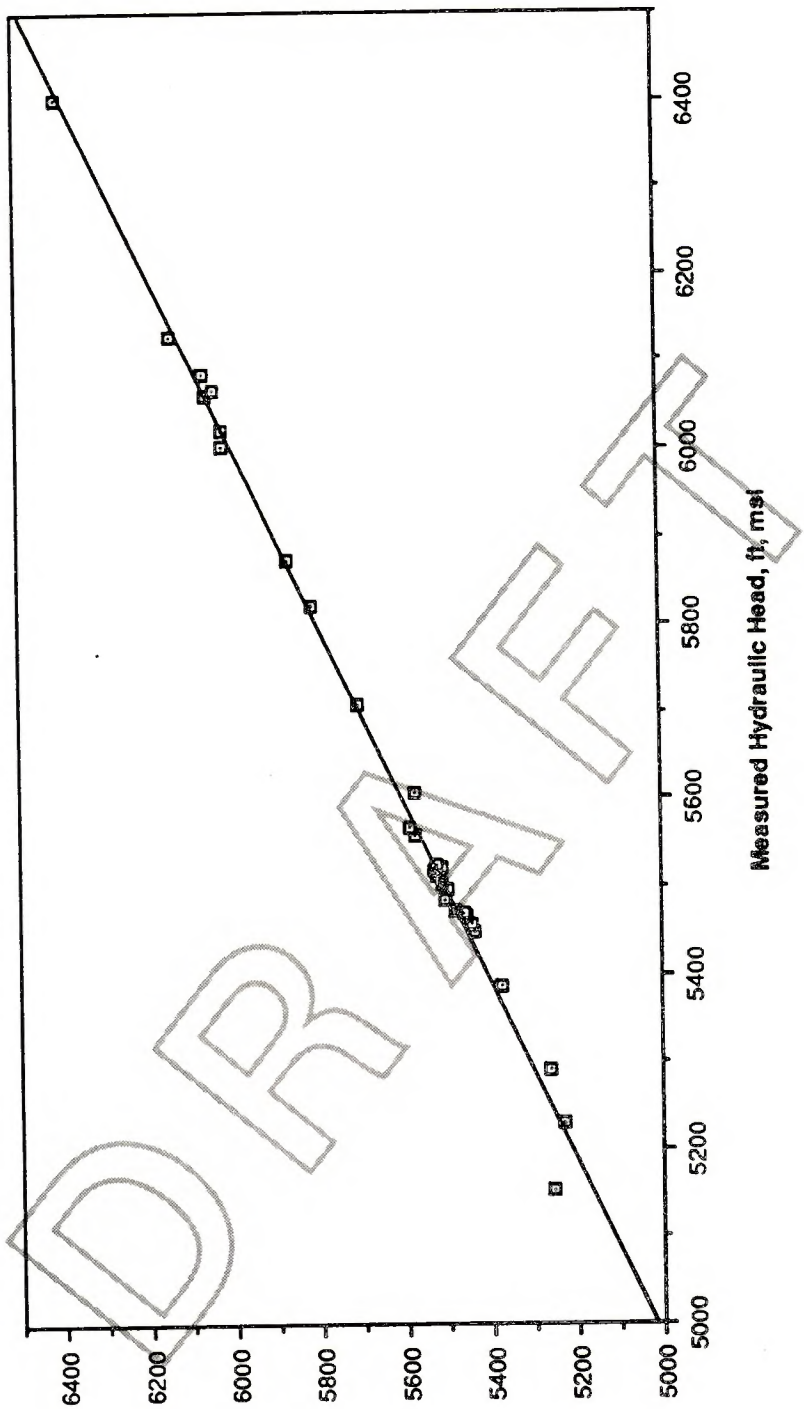
Project No. 90270B	Thousand Springs Power plant	MEASURED AND SIMULATED HYDRAULIC HEADS AT THE OBSERVATION NODES	Figure 8-5
Woodward-Clyde Consultants			



Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP BASED ON SIMULATED WATER LEVELS	Figure 8-6
Woodward-Clyde Consultants			



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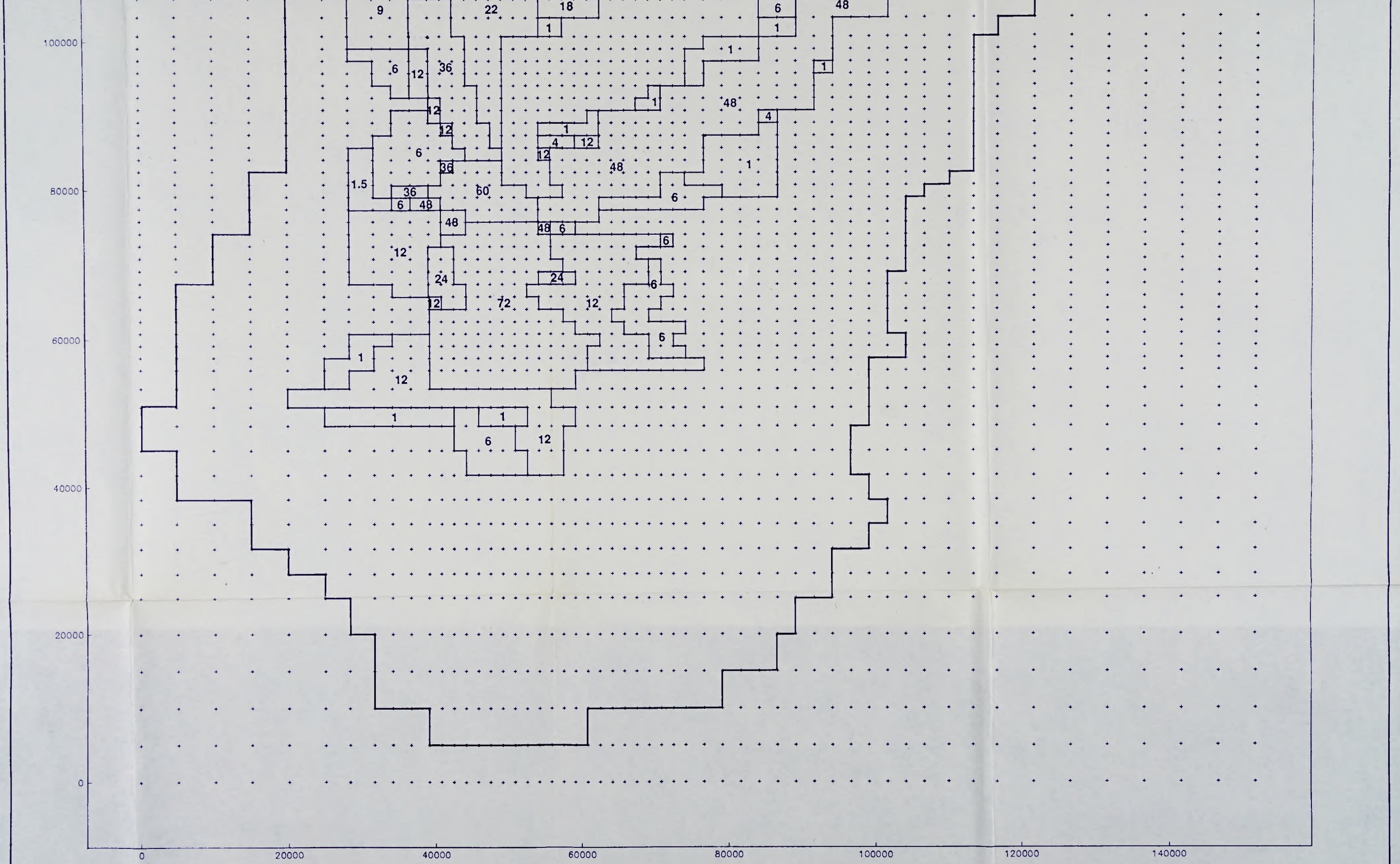
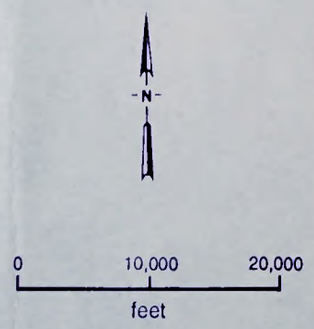
Project No. 90270B	Thousand Springs Power plant	MEASURED VERSUS SIMULATED HYDRAULIC HEADS	Figure 8-7
Woodward-Clyde Consultants			

180000
160000
140000
120000
100000
80000
60000
40000
20000





LEGEND

6 Hydraulic conductivity (feet/day)

Hydraulic Conductivity ≤ 0.1 feet/day

DISTRIBUTION OF CALIBRATED HYDRAULIC CONDUCTIVITIES

Project No. 90270B	Thousand Springs Power Plant	Figure 8-8
Woodward-Clyde Consultants		

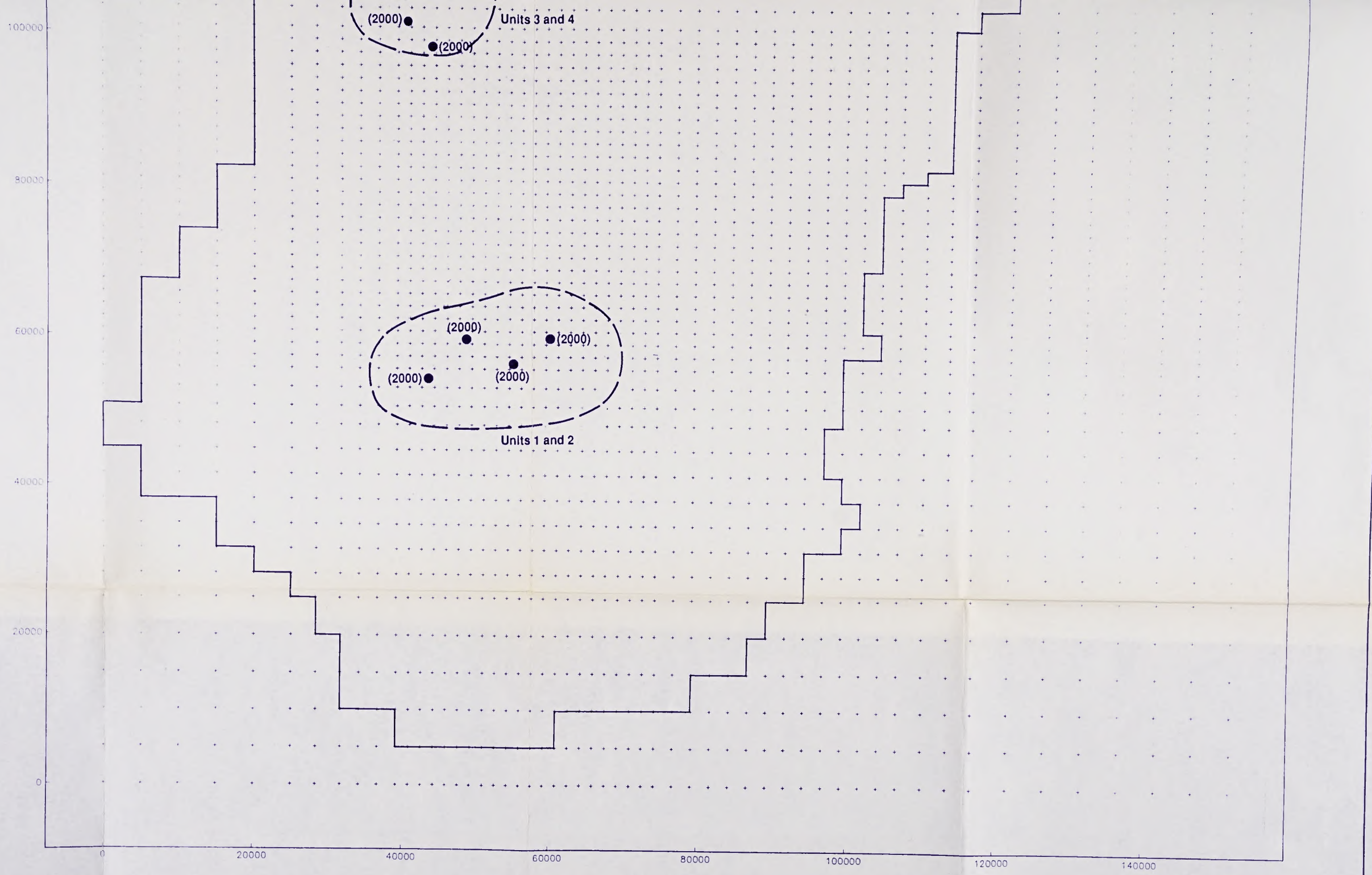
180000
160000
140000
120000
100000
80000
60000
40000
20000

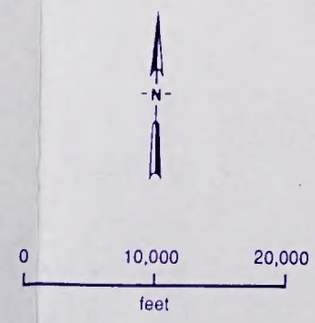
(1000)
(1000)
(1000)
(1000)
Unit 5

(2000)
(4000)
(2000)
Units 6 and 7

(2000)
(2000)
(2000)
(2000)
Units 3 and 4

(2000)
(2000)
(2000)
(2000)
Units 1 and 2





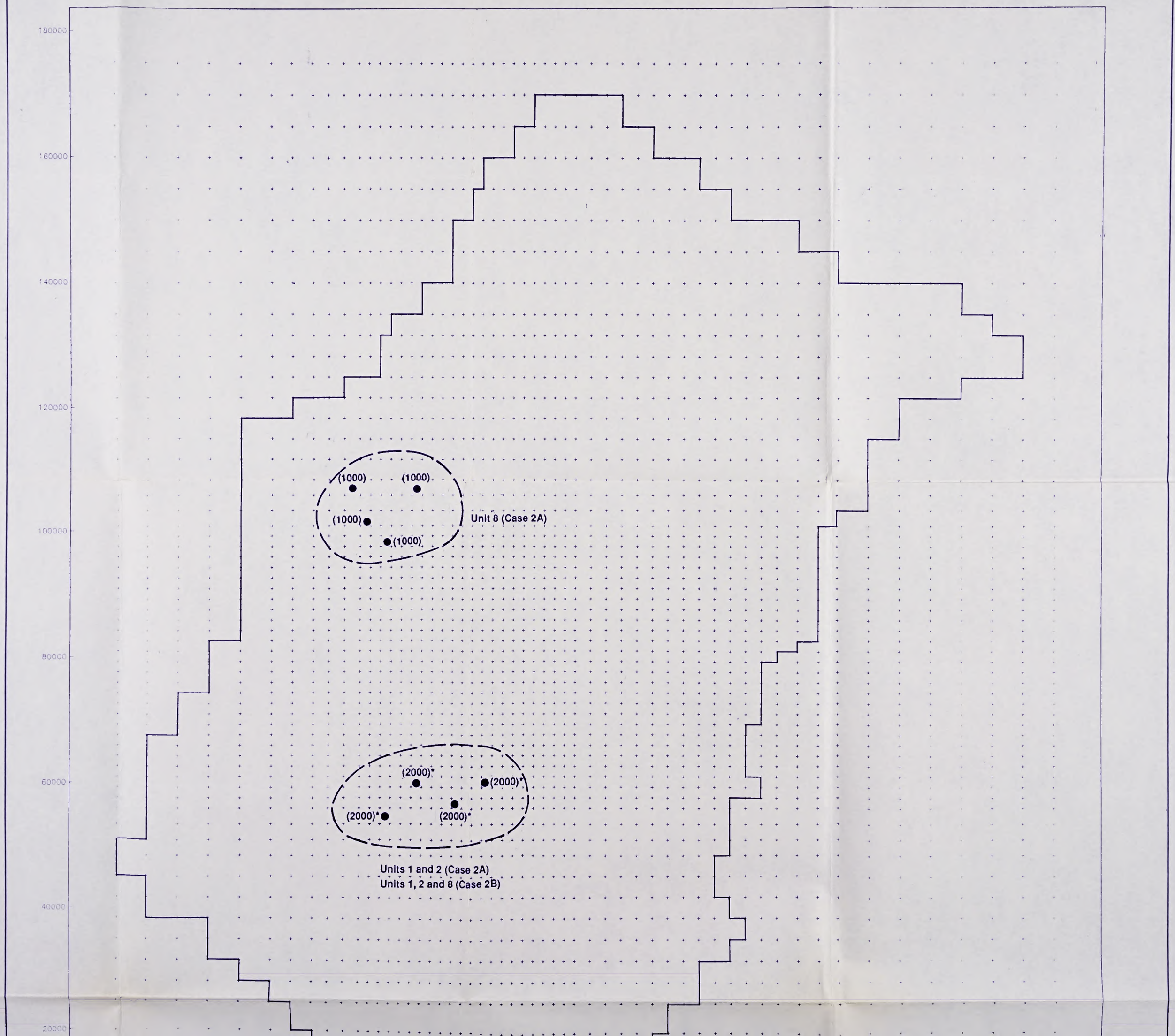
LEGEND

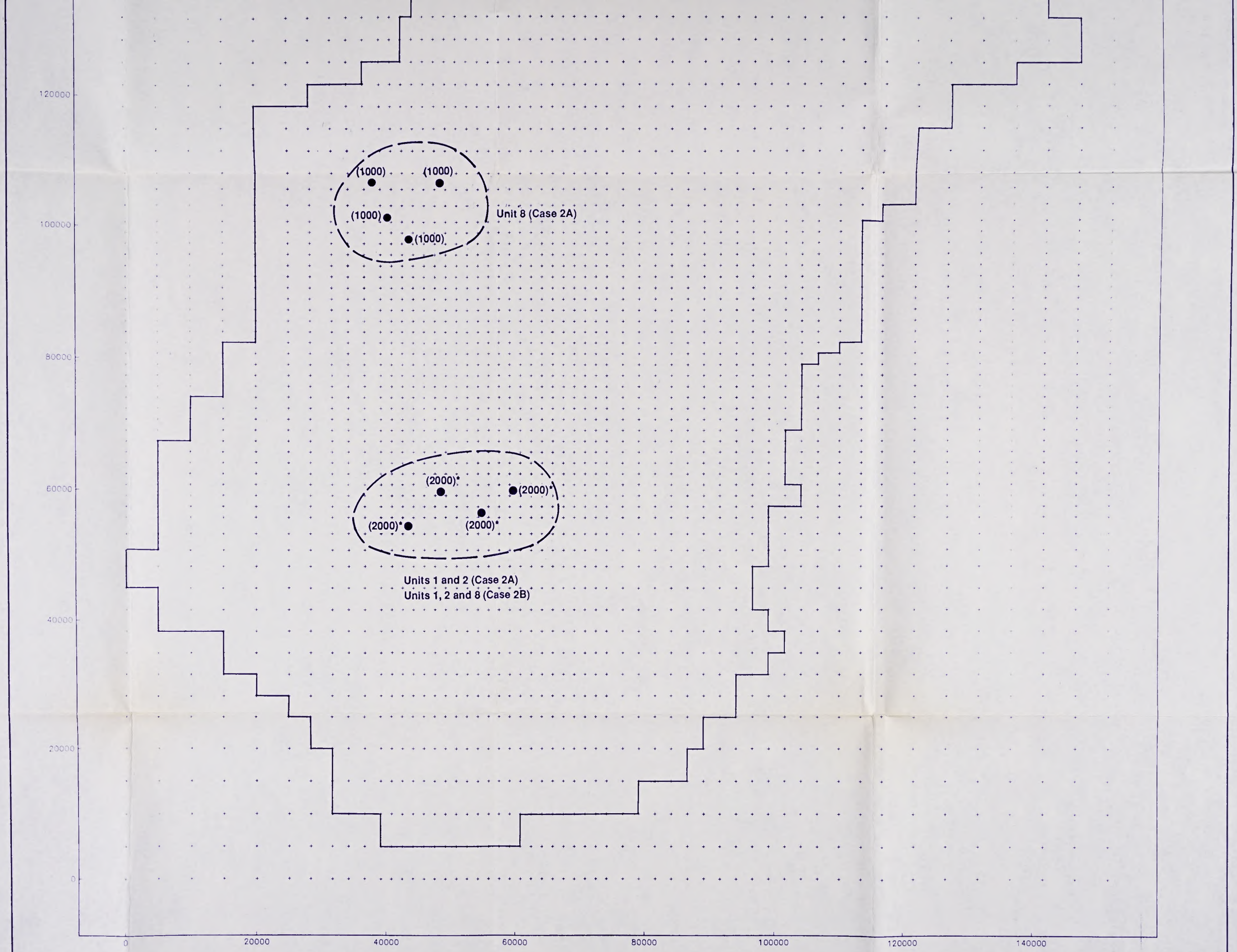
● Extraction well location

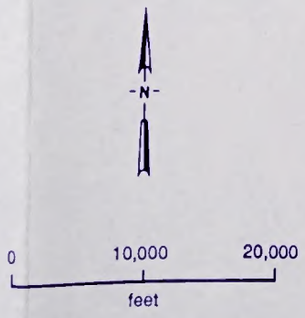
(2000) Pumping rate (acre-feet/year)

LOCATION OF EXTRACTION WELLS (Case 1)

Project No. 90270B	Thousand Springs Power Plant	Figure 8-9
Woodward-Clyde Consultants		


180000
160000
140000
120000
100000
80000
60000
40000
20000
(1000)
(1000)
(1000)
(1000)
Unit 8 (Case 2A)
(2000)*
(2000)*
(2000)*
(2000)*
Units 1 and 2 (Case 2A)
Units 1, 2 and 8 (Case 2B)



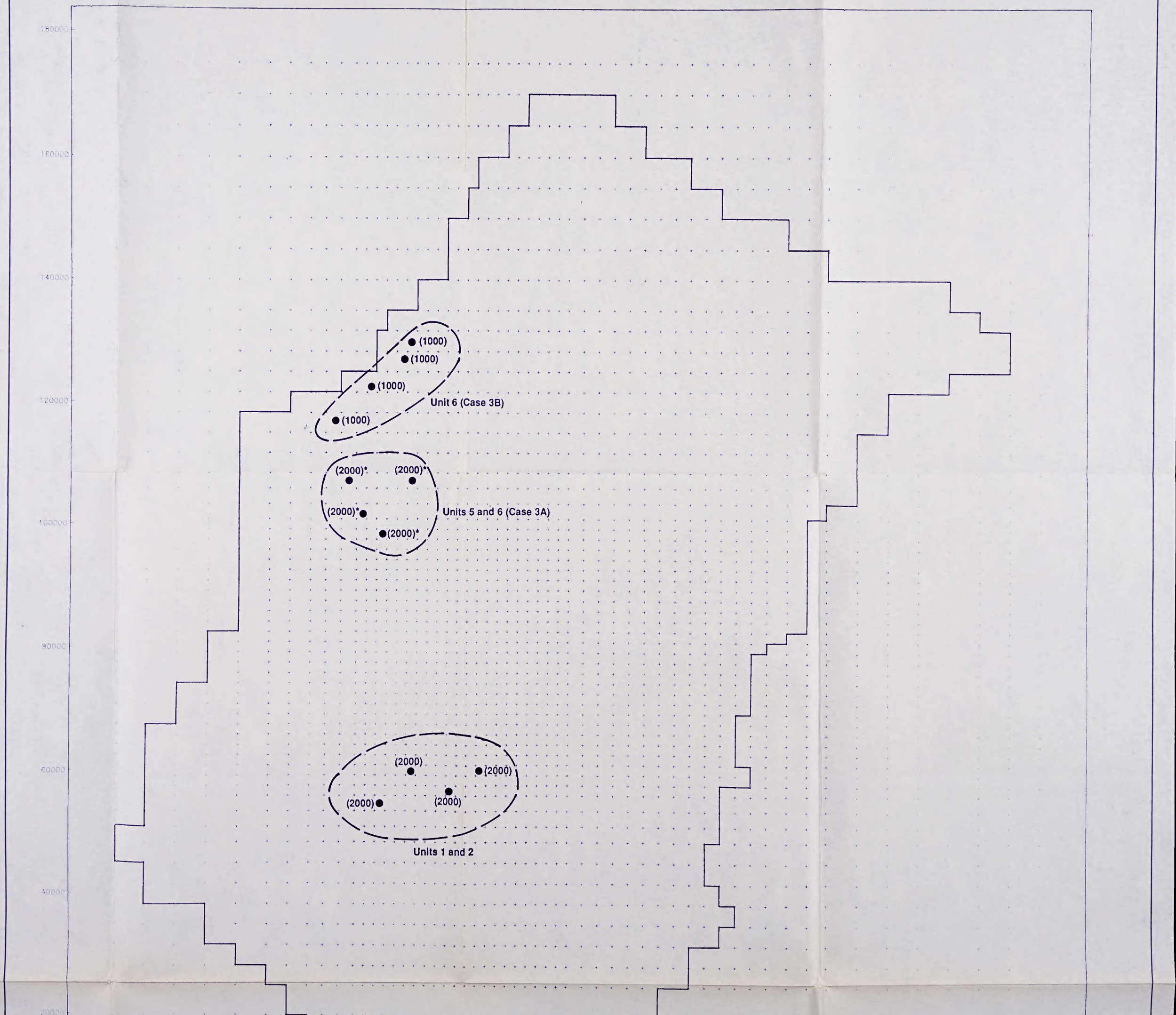


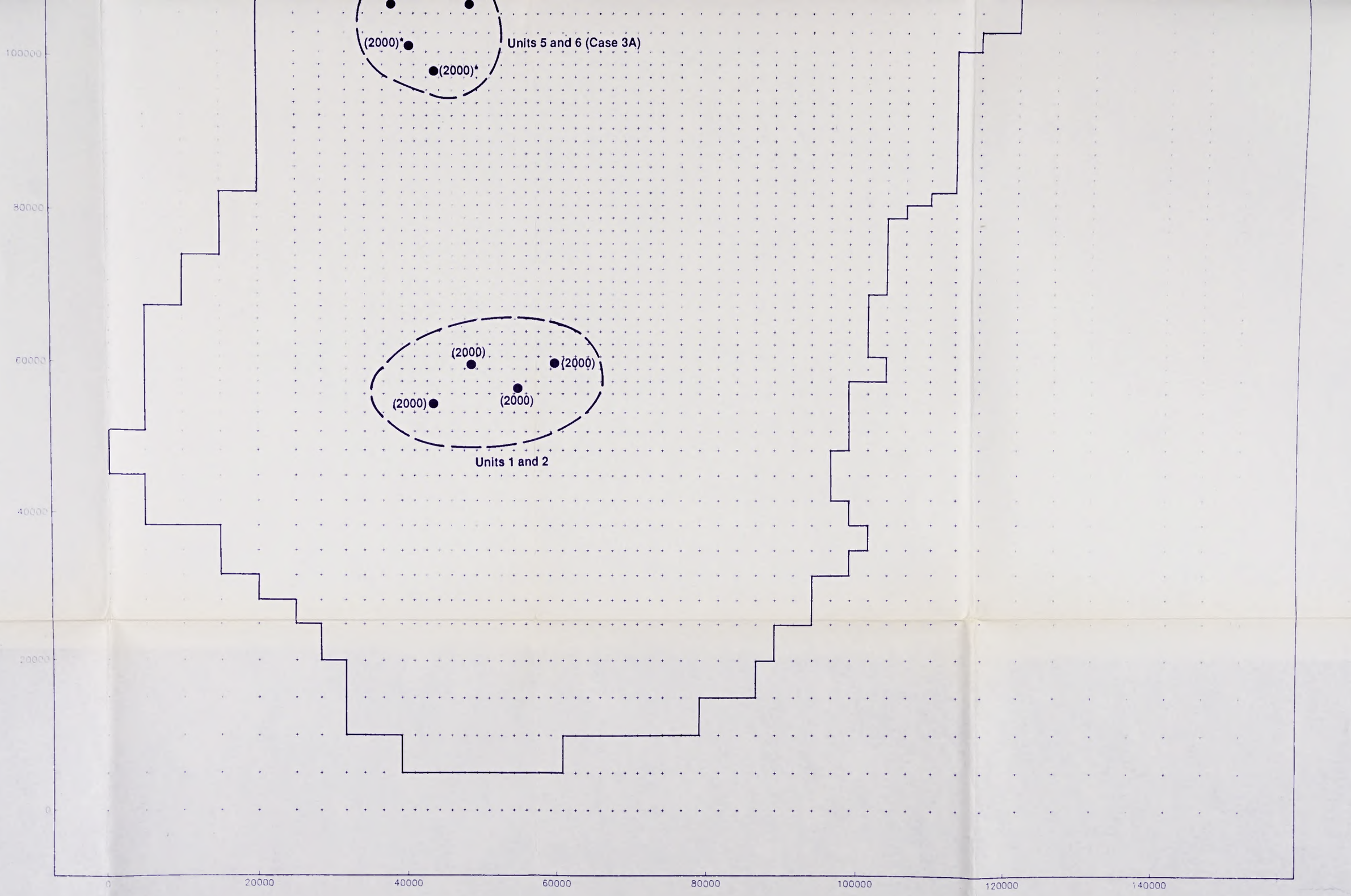
LEGEND

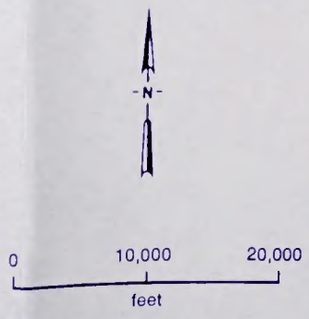
- ● Extraction well location
- (2000) Pumping rate (acre-feet/year)
- * Pumping rate is 3000 acre-feet/year for Case 2B

LOCATION OF EXTRACTION WELLS (Case 2)

Project No. 90270B	Thousand Springs Power Plant	Figure 8-10
Woodward-Clyde Consultants		


180000
160000
140000
120000
100000
80000
60000
40000
20000
(1000)
(1000)
(1000)
(1000)
Unit 6 (Case 3B)
(2000)*
(2000)*
(2000)*
(2000)*
Units 5 and 6 (Case 3A)
(2000)
(2000)
(2000)
(2000)
Units 1 and 2



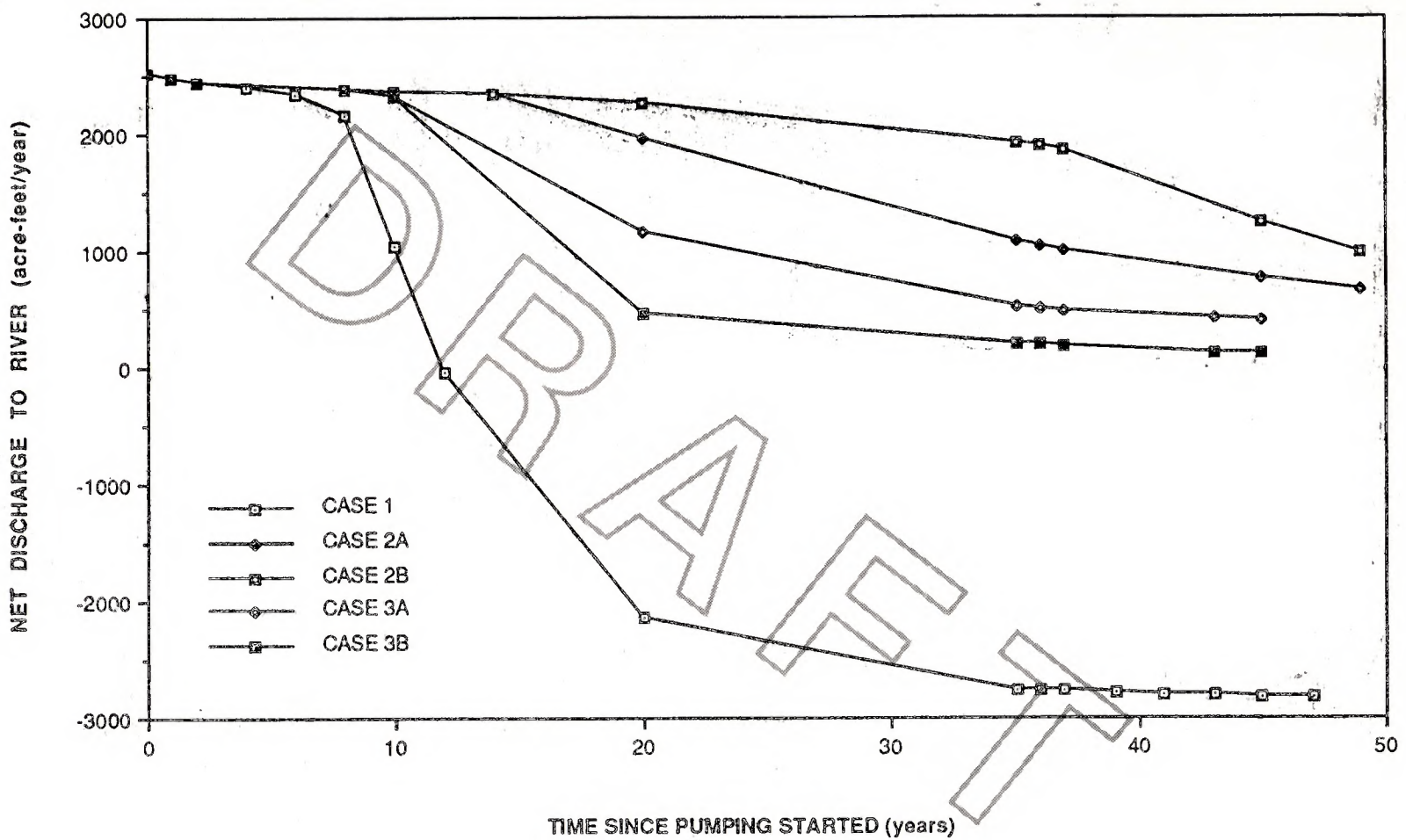


LEGEND

- ● Extraction well location
- (2000) Pumping rate (acre-feet/year)
- * Pumping rate is 1000 acre-feet/year for Case 3B

LOCATION OF EXTRACTION WELLS (Case 3)

Project No. 90270B	Thousand Springs Power Plant	Figure 8-11
Woodward-Clyde Consultants		



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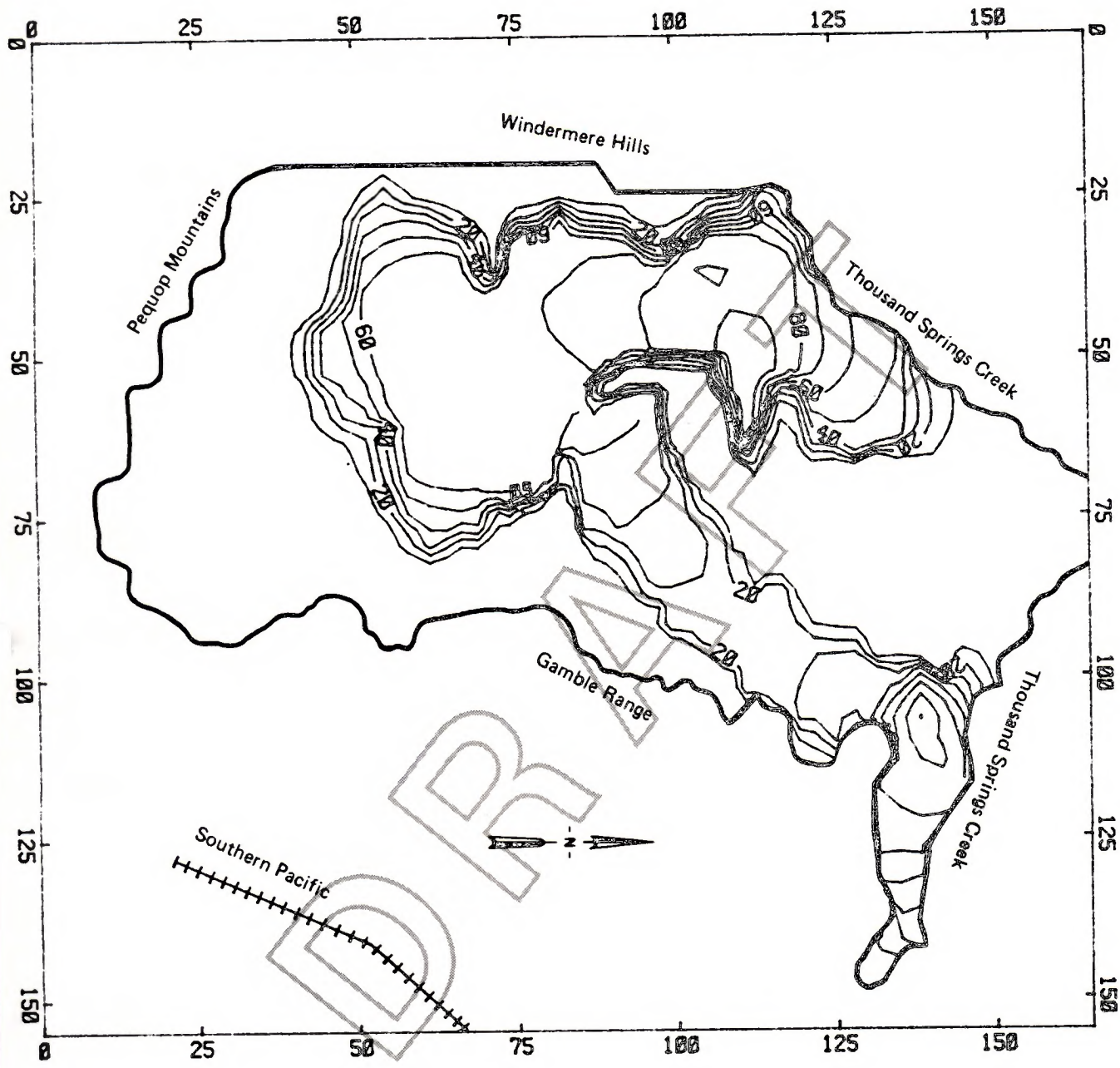
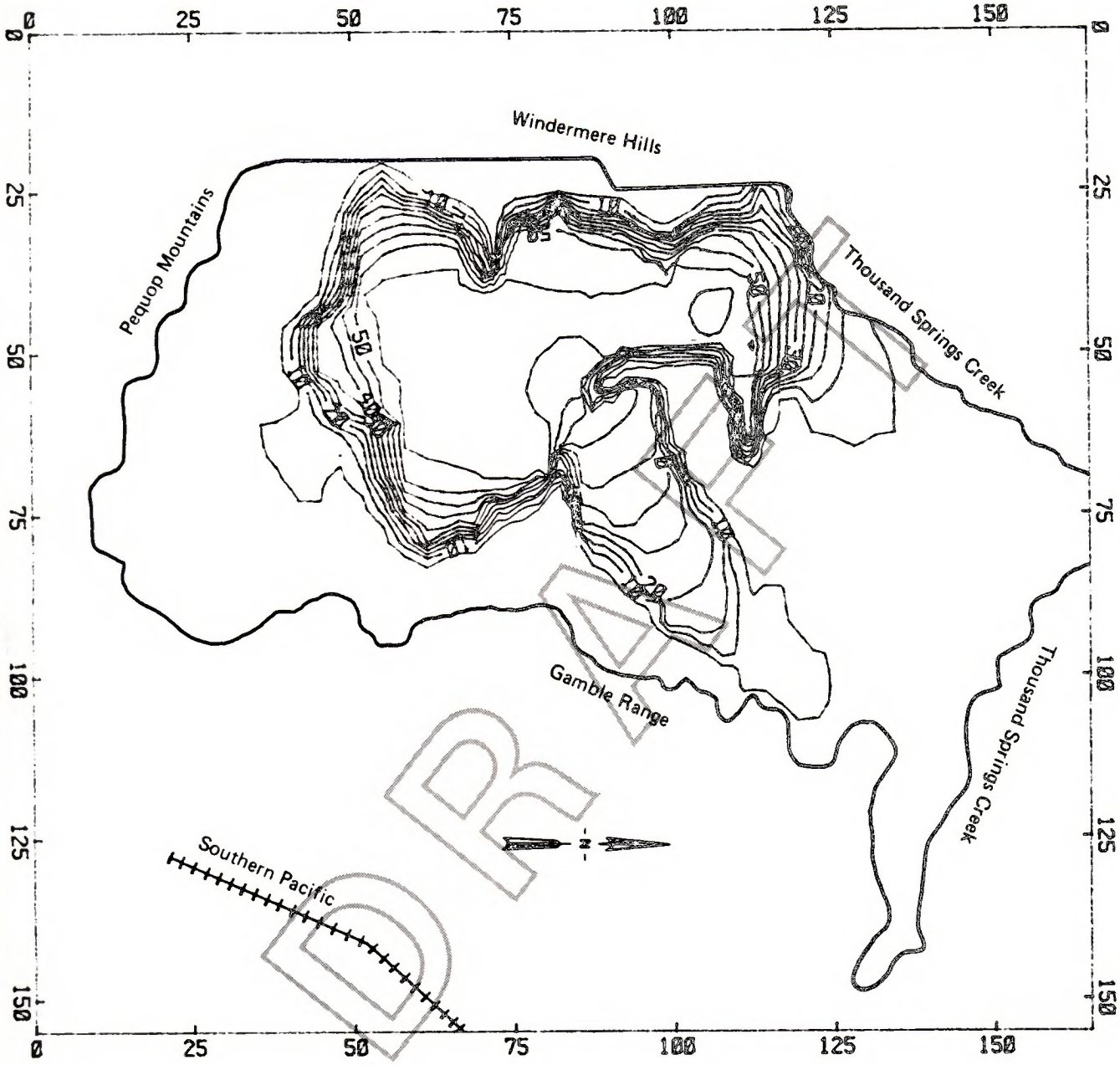
Project No. 90270B	Thousand Springs Power Plant	RATE OF WATER LOSS FROM THOUSAND SPRINGS CREEK FOR FIVE CASES OF GROUNDWATER DEVELOPMENT	Figure 8-12
Woodward-Clyde Consultants			



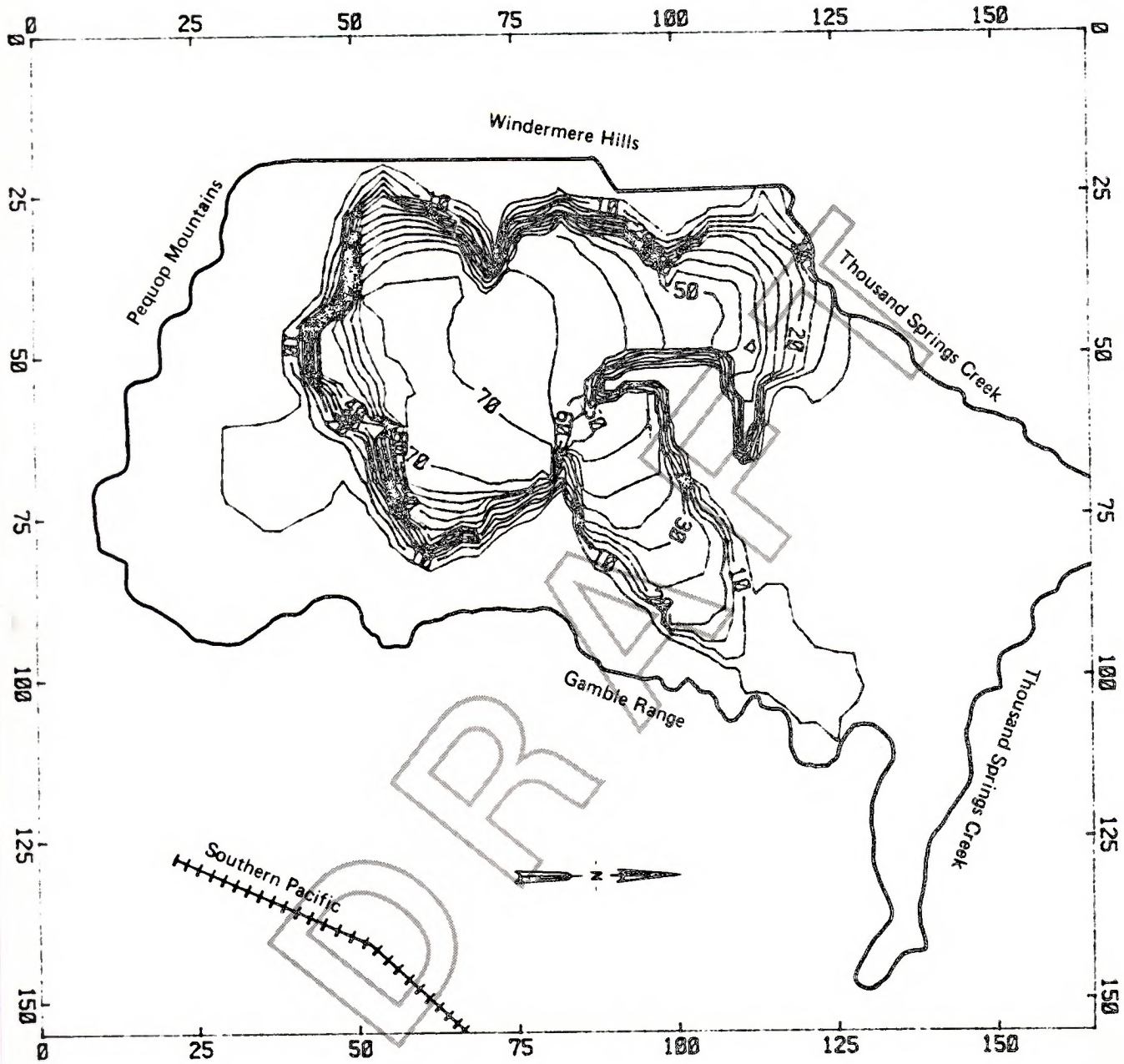
Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 1 AT THE END OF THE POWER PLANT'S USEFUL LIFE (47 YEARS)	Figure 8-13
Woodward-Clyde Consultants			



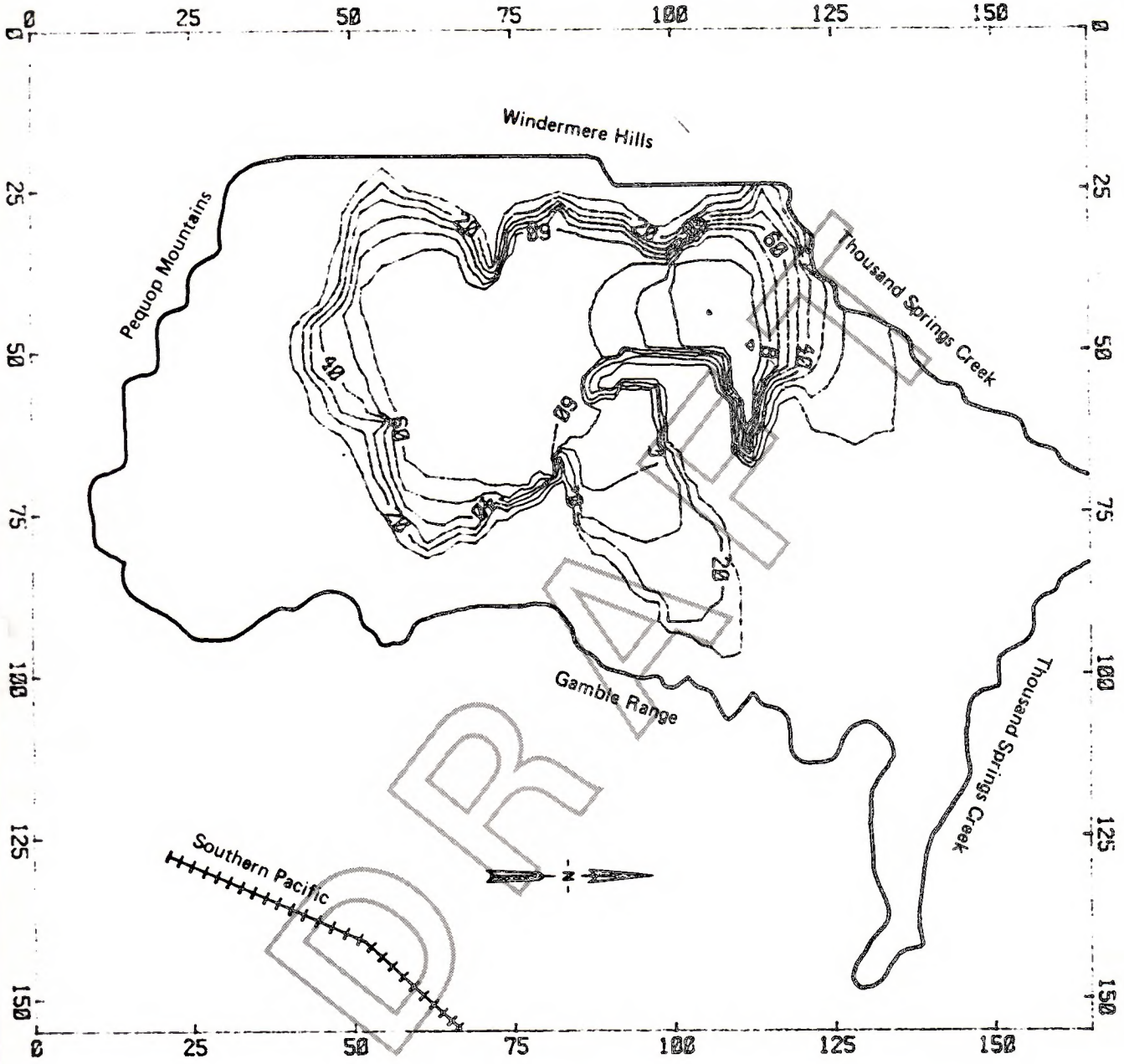
Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 2A AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-14
Woodward-Clyde Consultants			



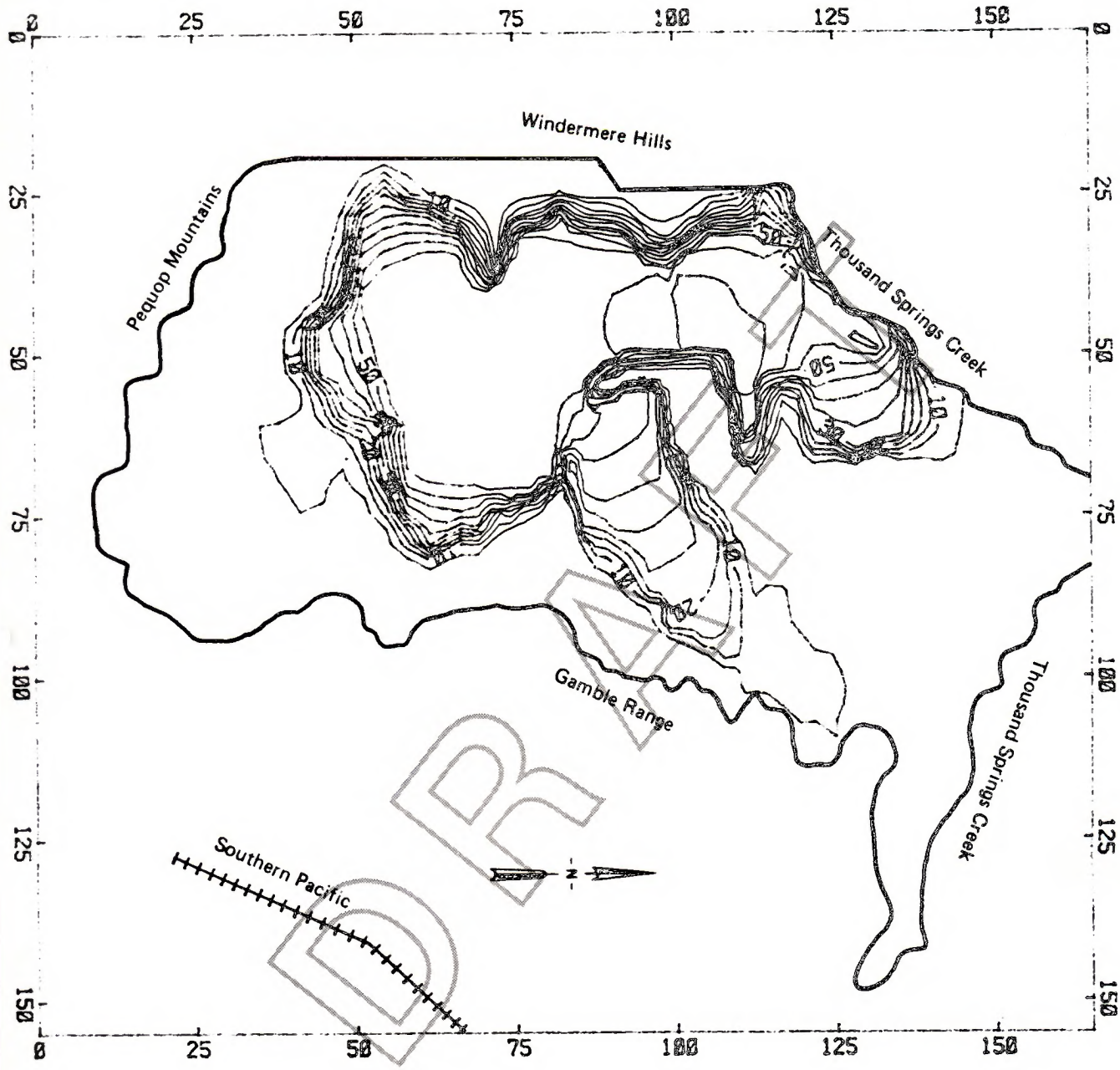
Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 2B AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-15
Woodward-Clyde Consultants			



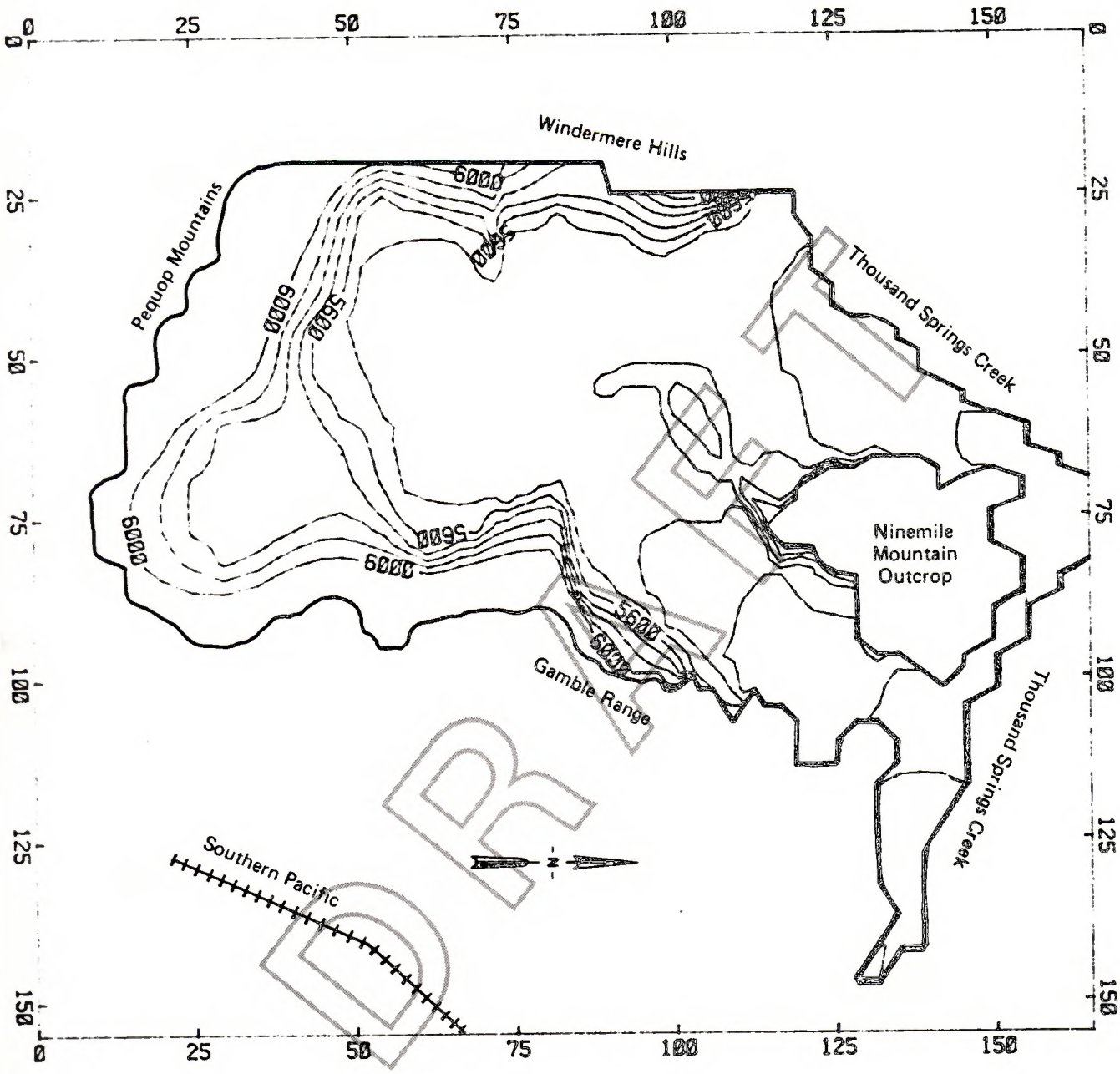
Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 3A AT THE END OF THE POWER PLANT'S USEFUL LIFE (45 YEARS)	Figure 8-16
Woodward-Clyde Consultants			



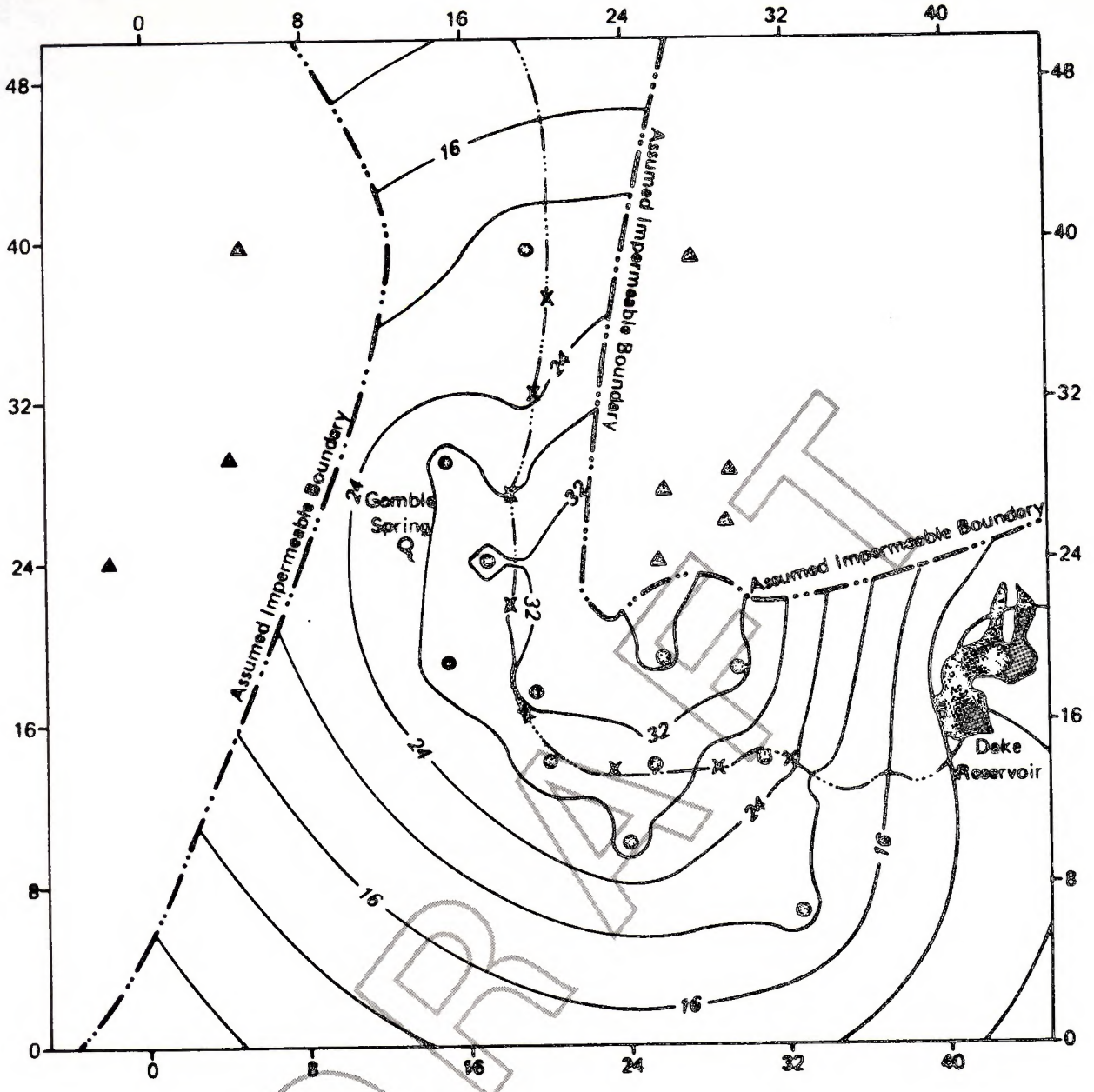
Scale 1:300,000

Project No. 902708	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 3B AT THE END OF THE POWER PLANT'S USEFUL LIFE (45 YEARS)	Figure 8-17
Woodward-Clyde Consultants			



Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP FOR CASE 2B AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-18
Woodward-Clyde Consultants			



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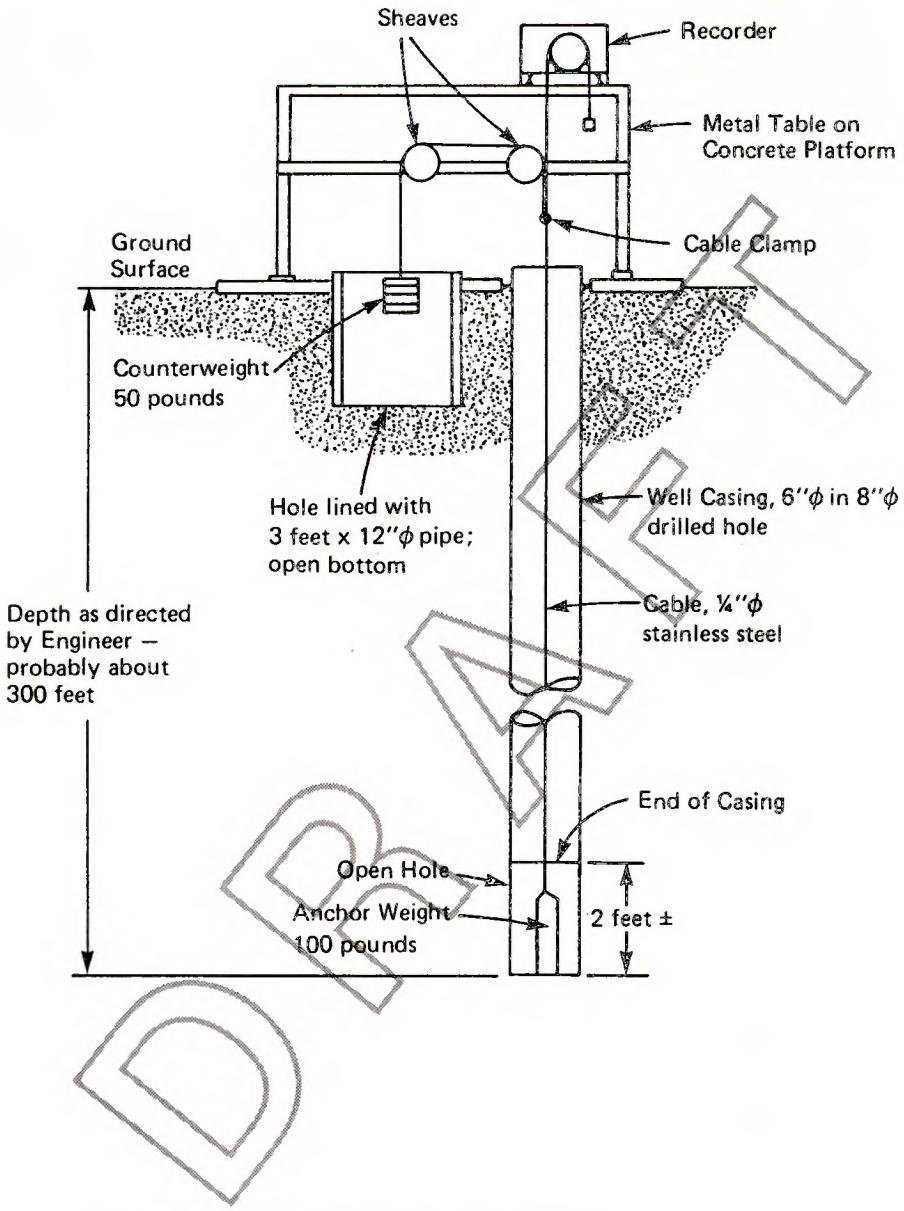
LEGEND

- ● Pumping Well (1040 gpm)
- ▲ Image Discharge Well (1040 gpm)
- ◉ Leakage from Dake Reservoir (2500 gpm)
- X Leakage from Thousand Springs Creek (700 gpm)
- —·—·— Assumed Impermeable Boundary
- —···— Thousand Springs Creek
- —16— Drawdown (feet)

N

Scale 1:100,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR MONTELLO VALLEY AFTER 35 YEARS OF PUMPING 20,000 ACRE-FEET/YEAR	Figure 8-19
Woodward-Clyde Consultants			



Note: Shelter required over this installation not shown.

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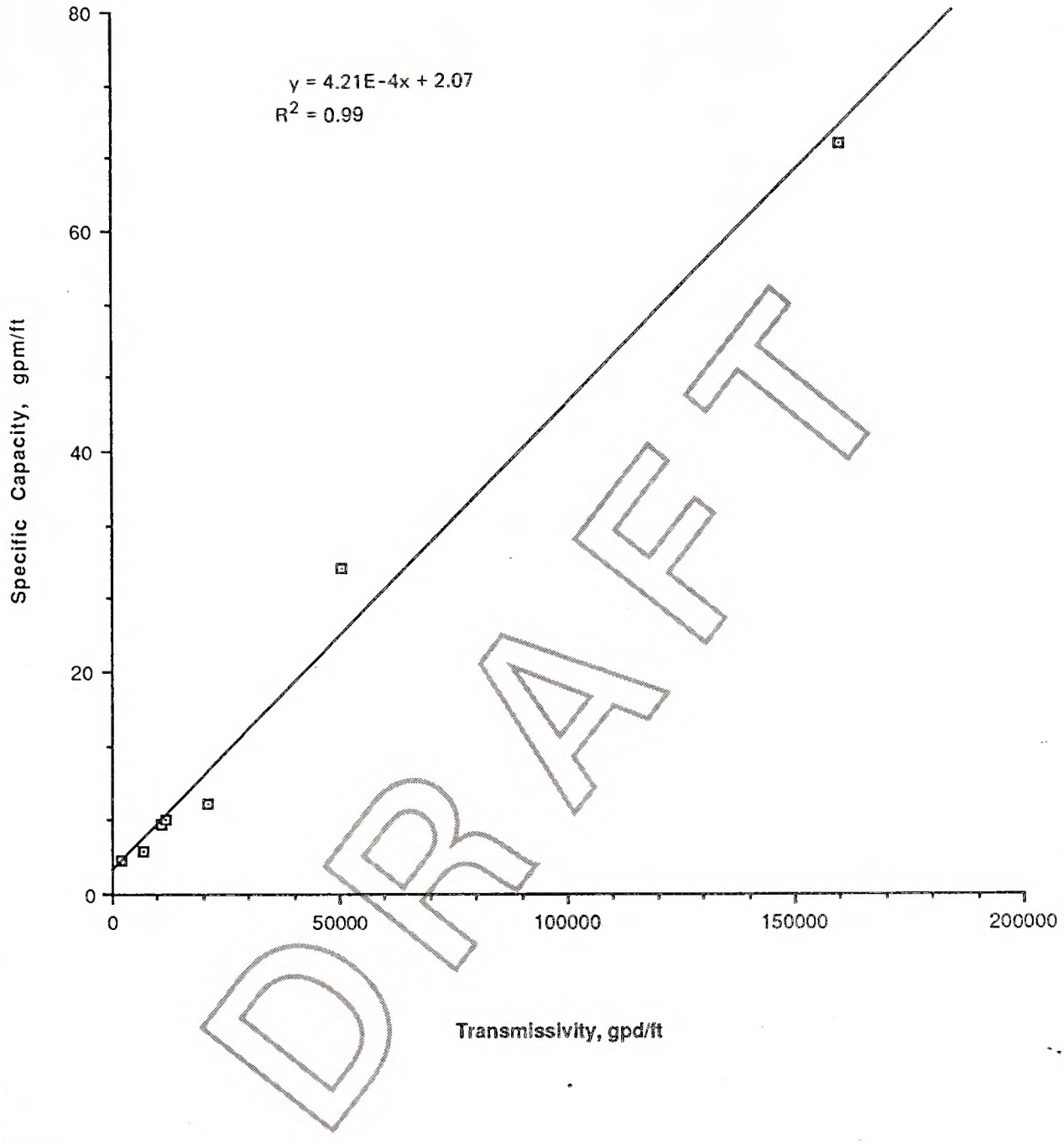
Project No. 90270B	Thousand Springs Power Plant	SUBSIDENCE MONITORING RECORDER	Figure 11-1
Woodward-Clyde Consultants			



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Project No. 90270B	Thousand Springs Power Plant	CORRELATION OF SPECIFIC CAPACITIES OF WELLS TO AQUIFER TRANSMISSIVITIES	Figure 4-19
Woodward-Clyde Consultants			